Dark matter searches with the LUX and LUX-ZEPLIN detectors

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LUX and LZ Collaborations

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The LUX detector is done detecting.

The primary result is out.
So is the detector.

Taking stock

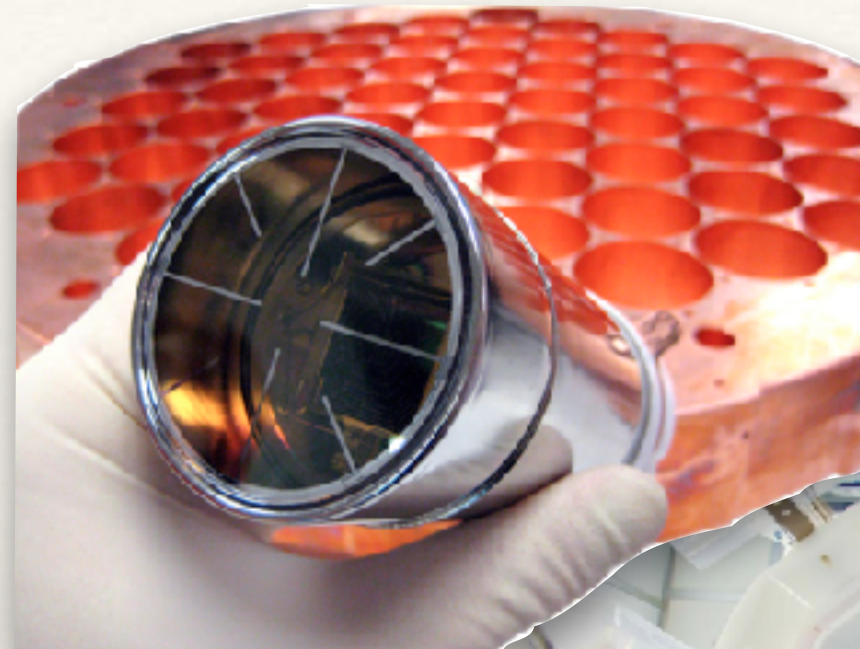
- a new standard for detector calibrations
- world-leading SI WIMP-nucleon exclusion accepted for publication
- demonstrated operations of 100s-kg-to-ton-scale detector at SURF
- more physics results to come!

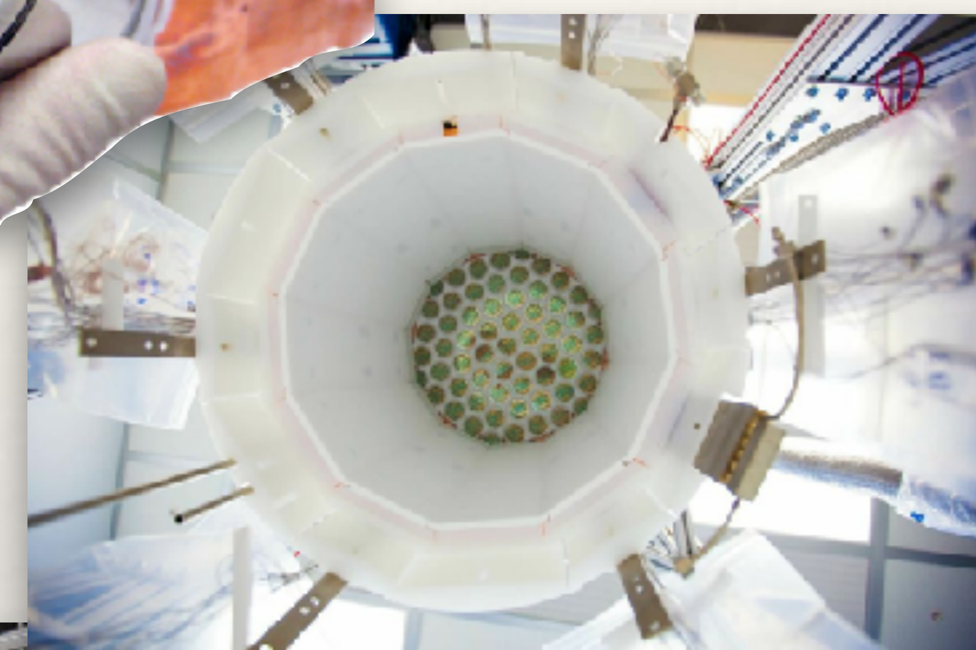
Snippet taken from https://www.youtube.com/watch?v=SkM3N7f6LoE

…and now we look forward to LZ

The LUX detector

- 122 Hamamatsu photomultiplier tubes—61 in top and bottom arrays
  - optimized for 175nm sensitivity
  - made for LUX's cryogenic and low-BG needs (R8778)
- Dodecagonal active volume with 0.5 m "diameter" (face to face), 0.5 m height (cathode to gate)
- Interior paneling (PTFE) maximizes light collection
  - highly reflective (>99%) for 175 nm in LXe
- Active LXe mass: 250 kg

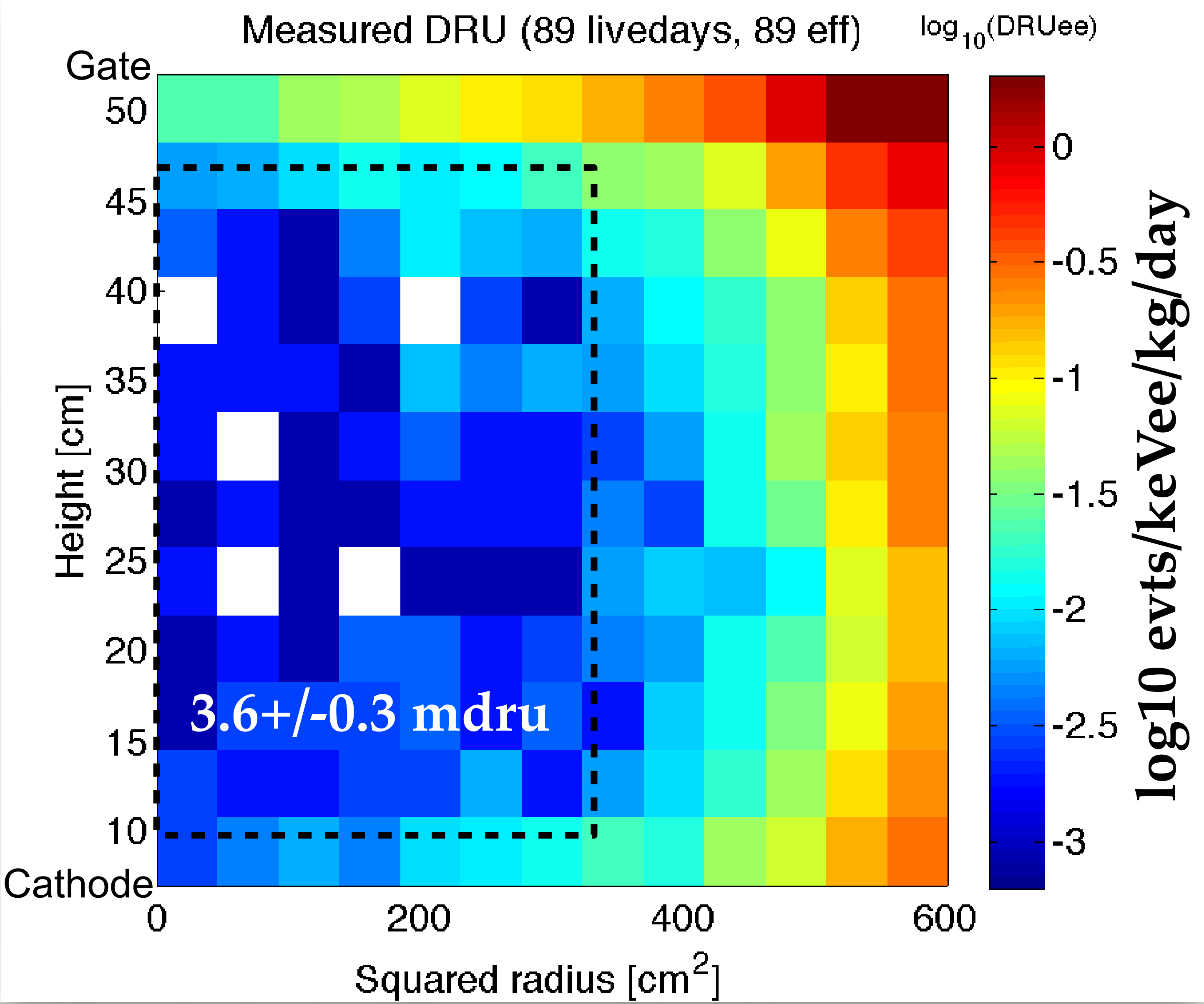




Background minimization in LUX

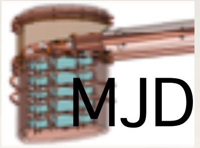
- Internal
  - We count and then build with low-background materials (Cu, Ti)
  - Fiducialization takes advantage of xenon's "self-shielding"
    - Come inside ~few cm of LXe, away from radioisotopes in materials and Rn plate-out on surfaces.
- Intrinsic
  - Dedicated purification system for Kr removal from Xe via chromatographic separation.
    - Avoid ^{85}Kr (beta decay)
- External
  - 70,000-gallon water tank with active PMT veto system for muon tagging
  - Overburden for reduction of cosmic backgrounds

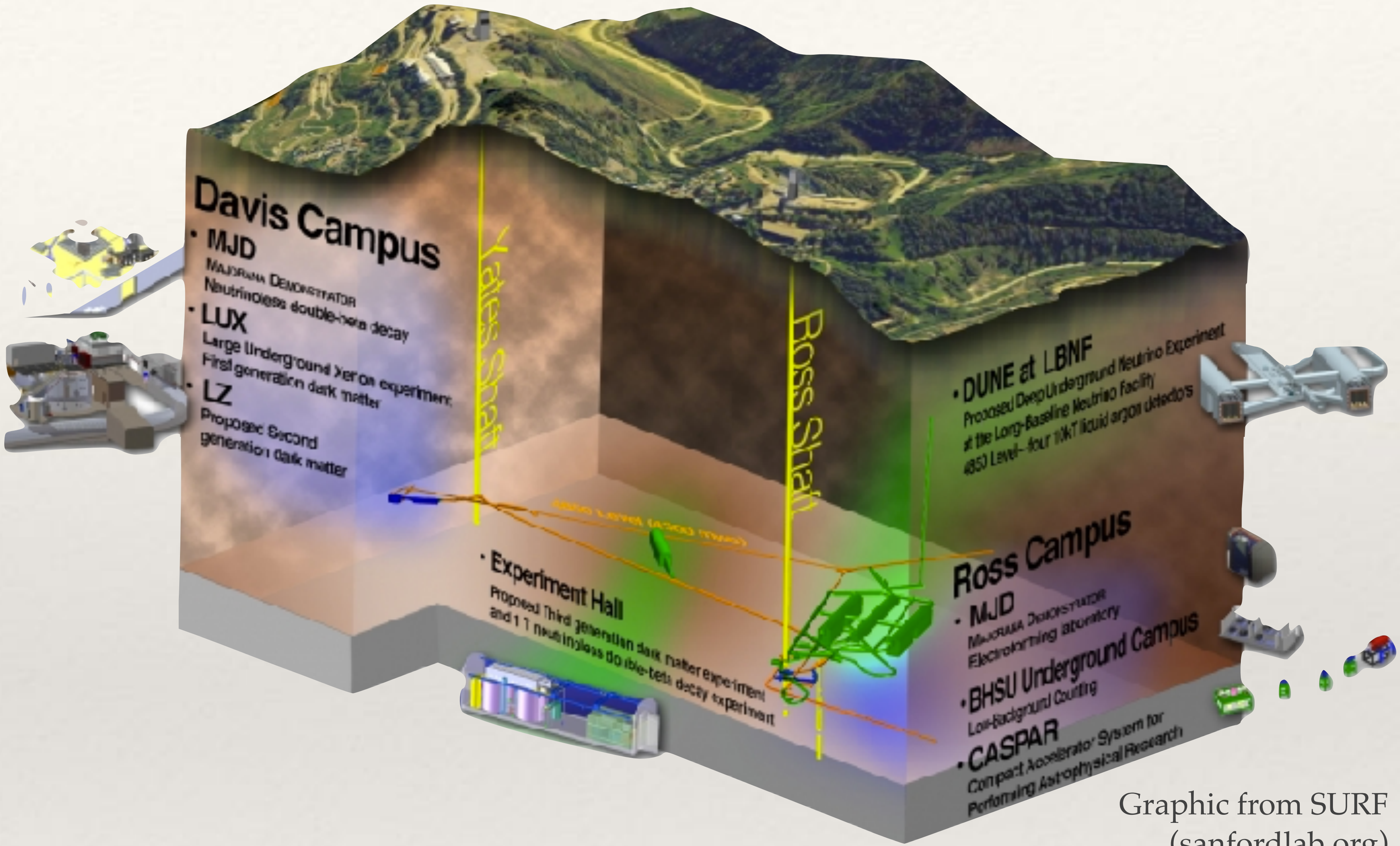
Example of LXe Self-Shielding from LUX2013 Data



Sanford Underground Research Facility

- LUX ran (LZ will run) in the LBNL-operated Sanford Underground Research Facility in Lead, South Dakota.
- Next door to the Majorana Demonstrator on the 4850′ level of SURF

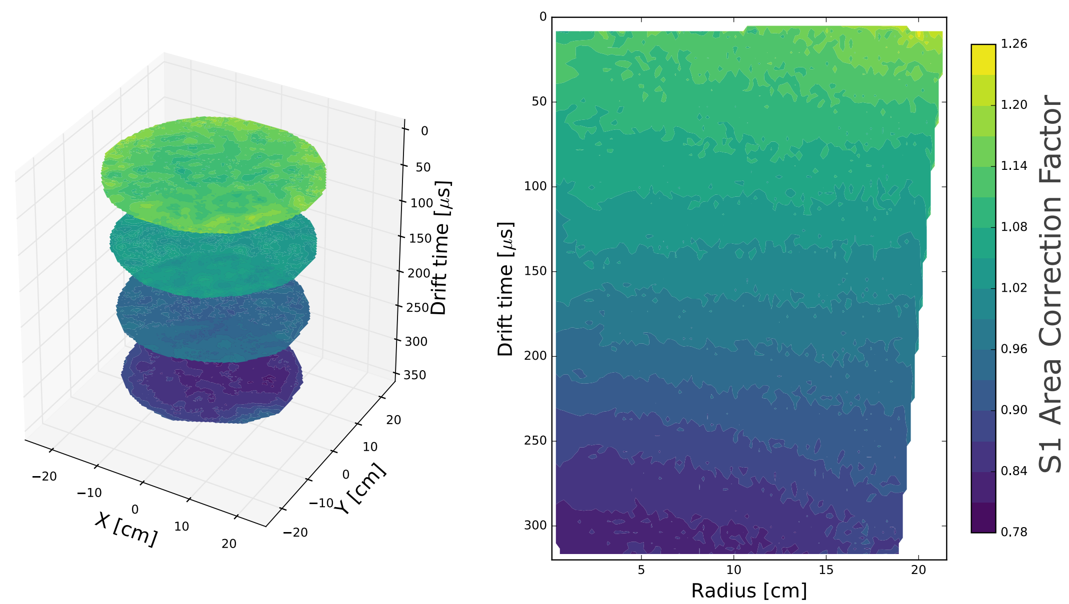




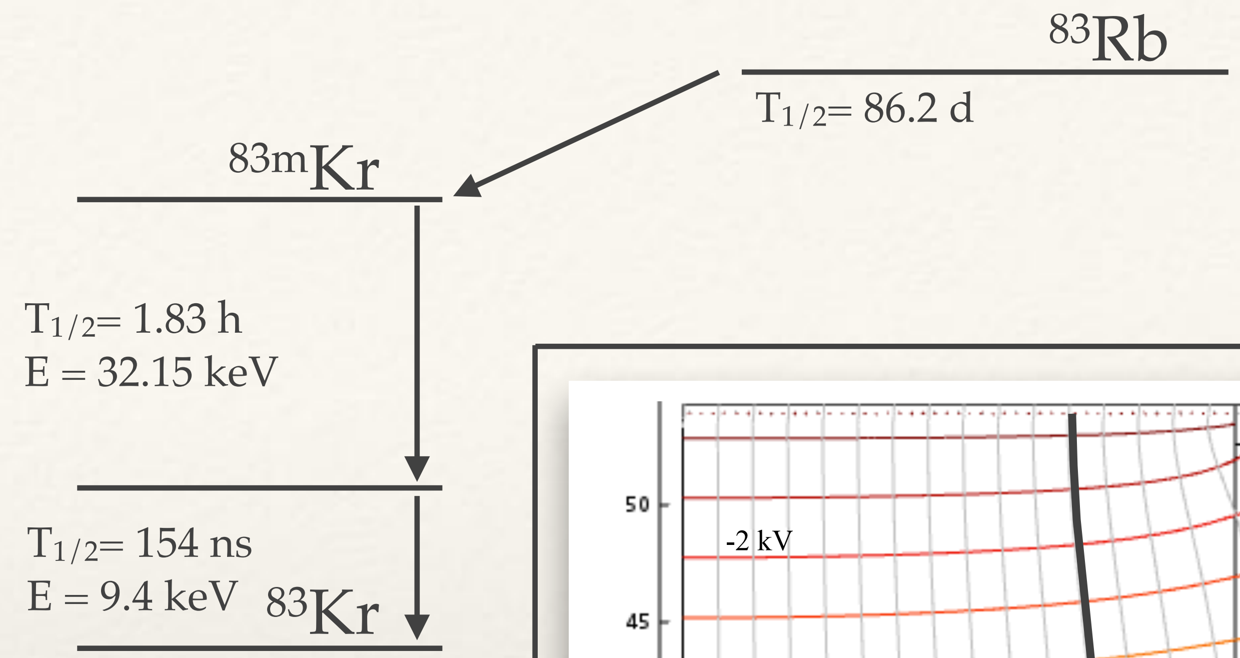
Graphic from SURF (sanfordlab.org)

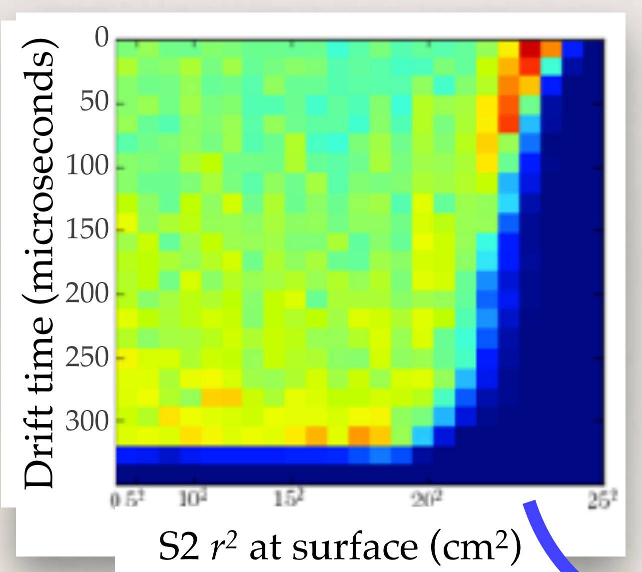
The Davis Cavern, part of the 4850′ level of SURF, offers a factor of **~10^7 reduction** in the rate of cosmic muons.

Calibration #1: ^{83m}Kr

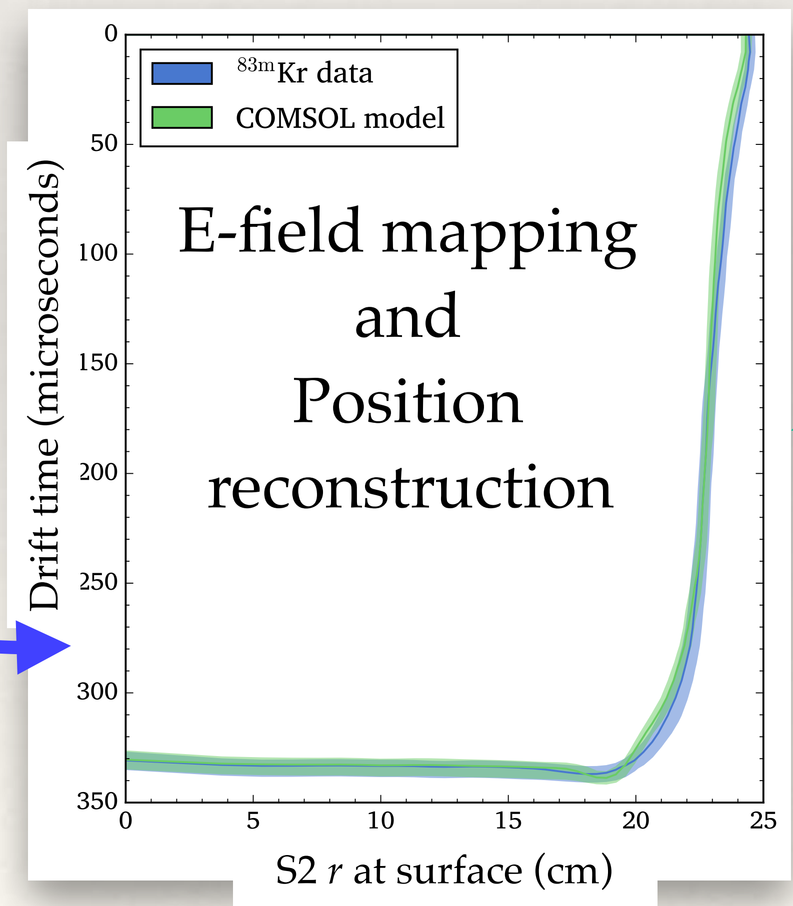


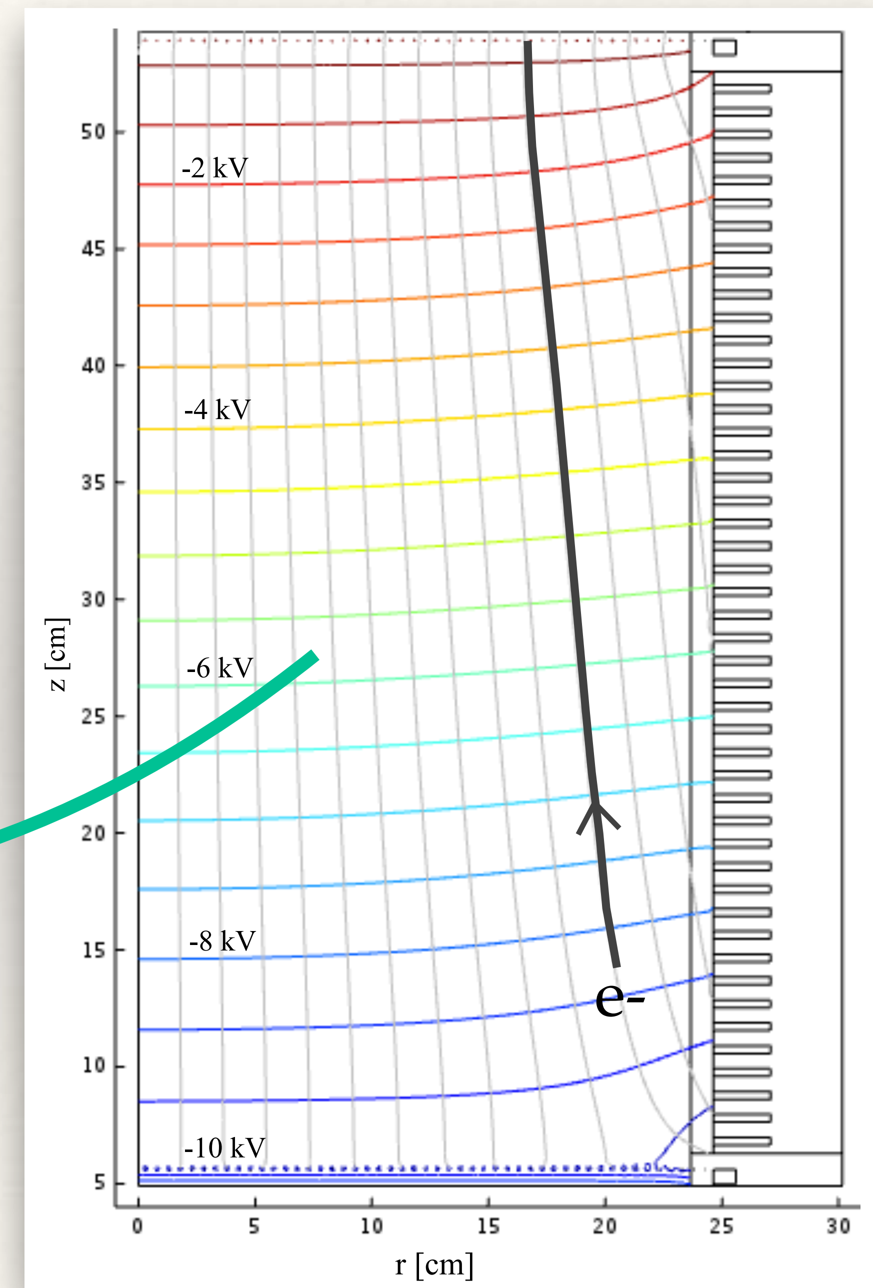
Pulse area normalization





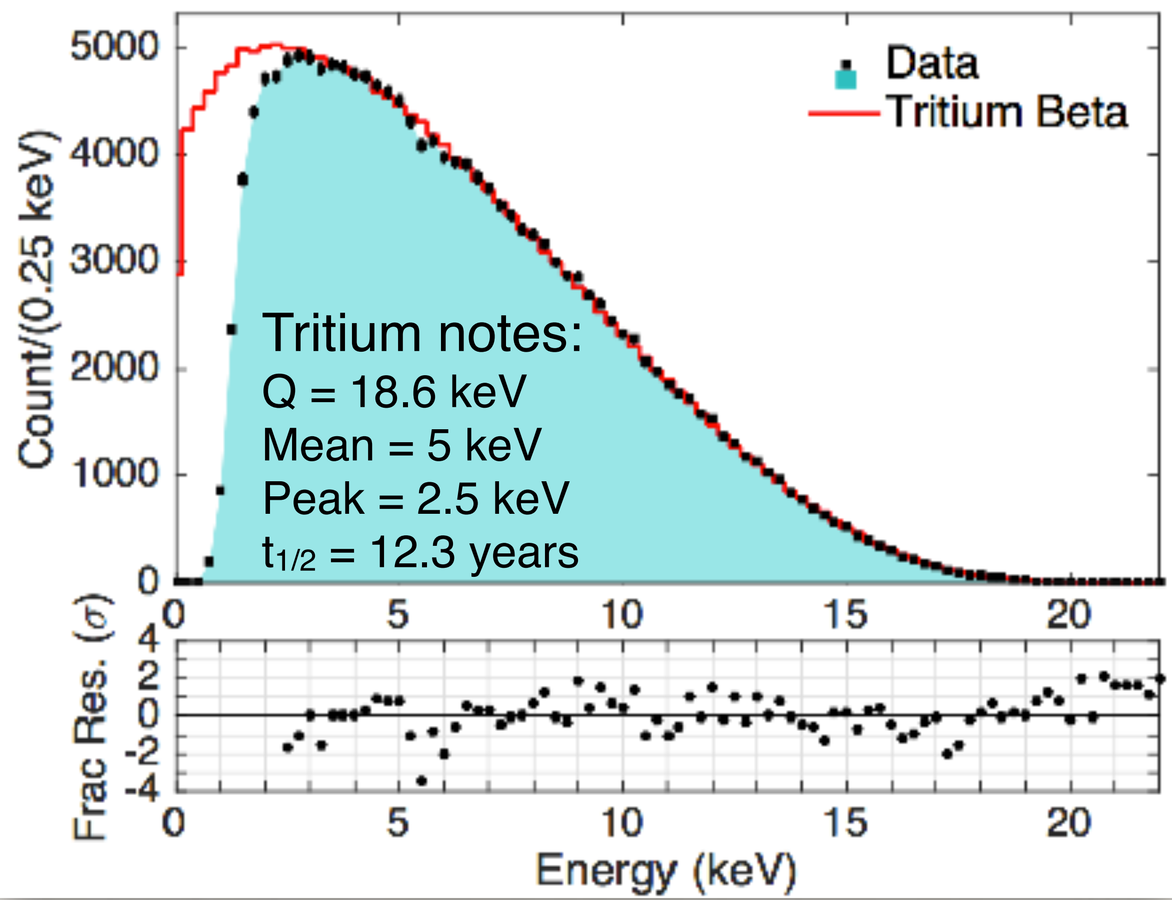
Trace the edge of the ^{83m}Kr (r,drift) event distribution to map the edge of the detector's active region into S2 coordinates

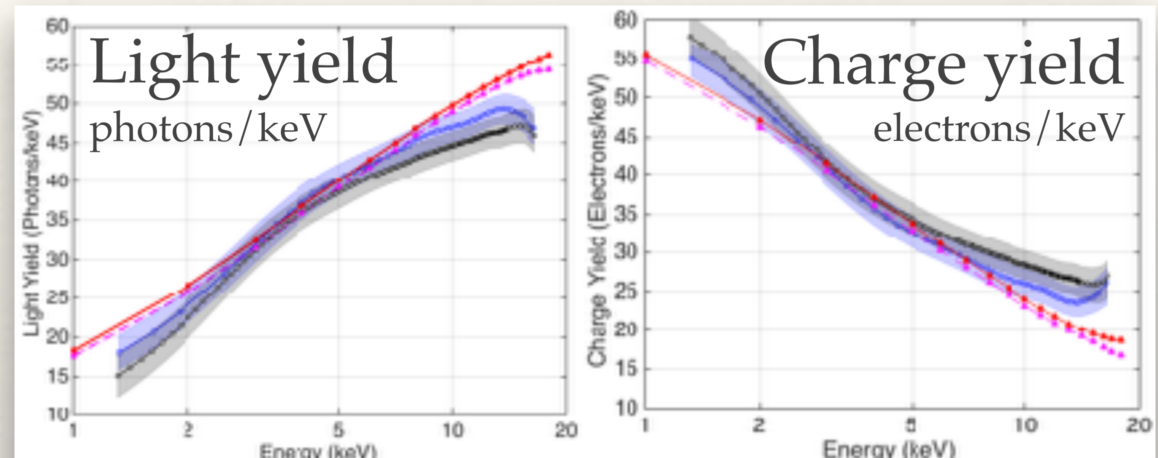


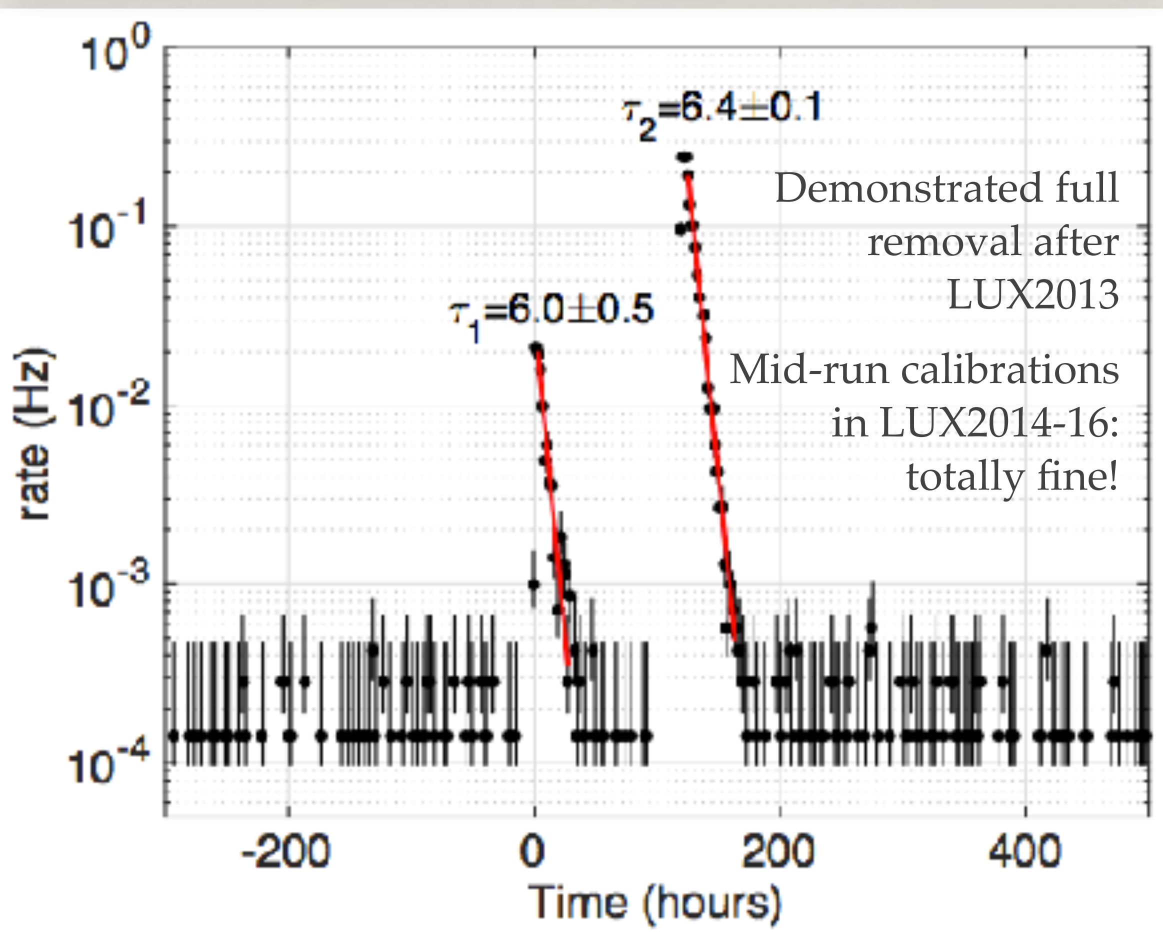


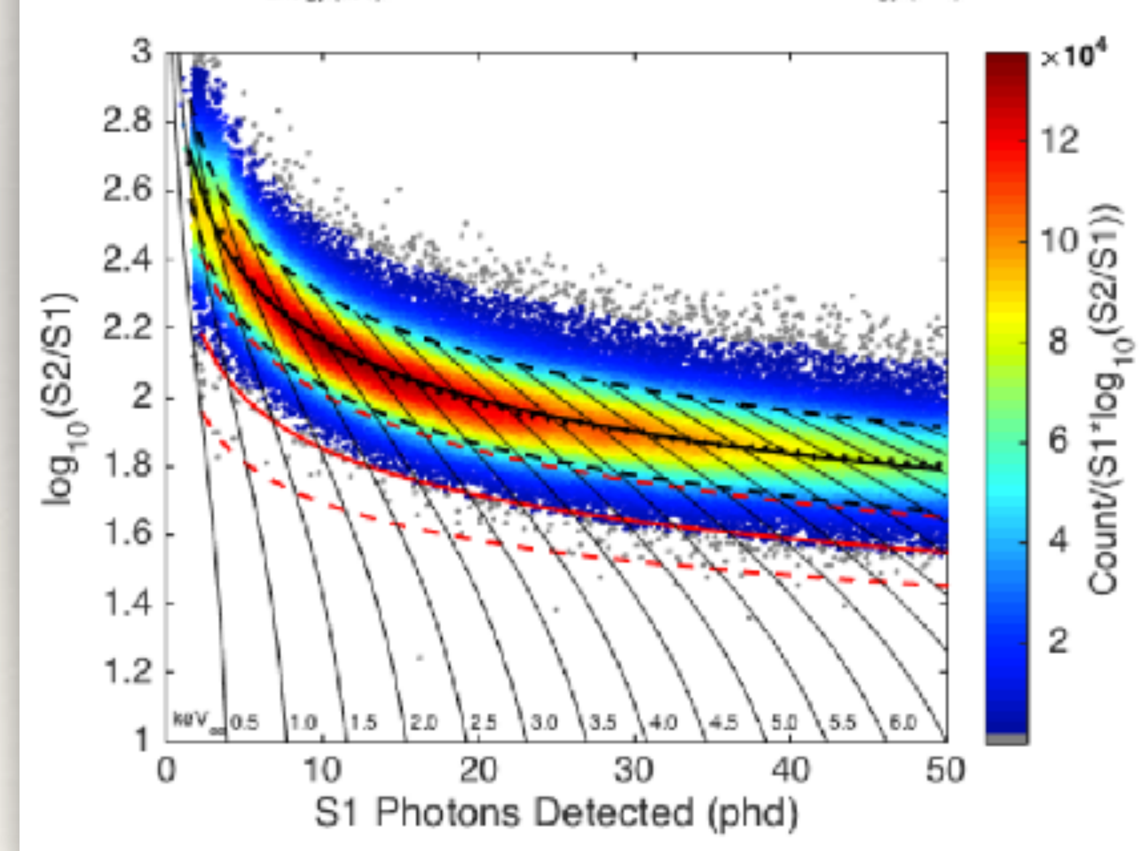
Calibration #2: ^{3}H

The reliable injection *and removal* of tritiated methane for electronic recoil calibration and yields measurements



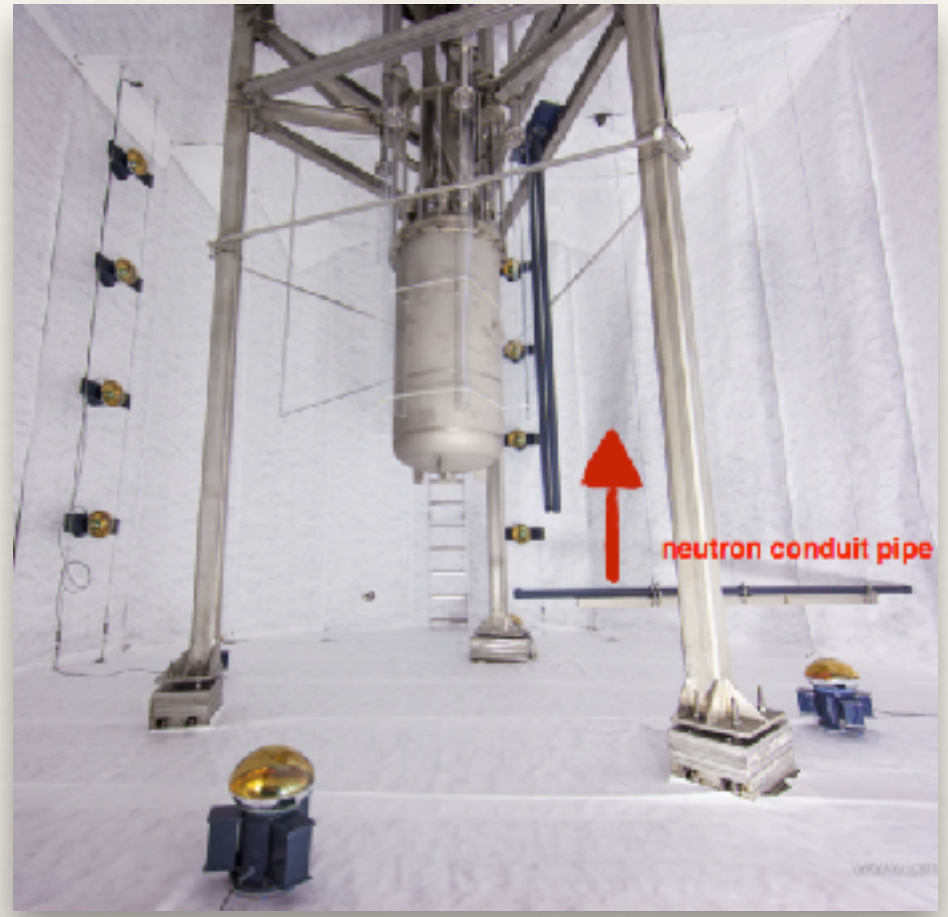


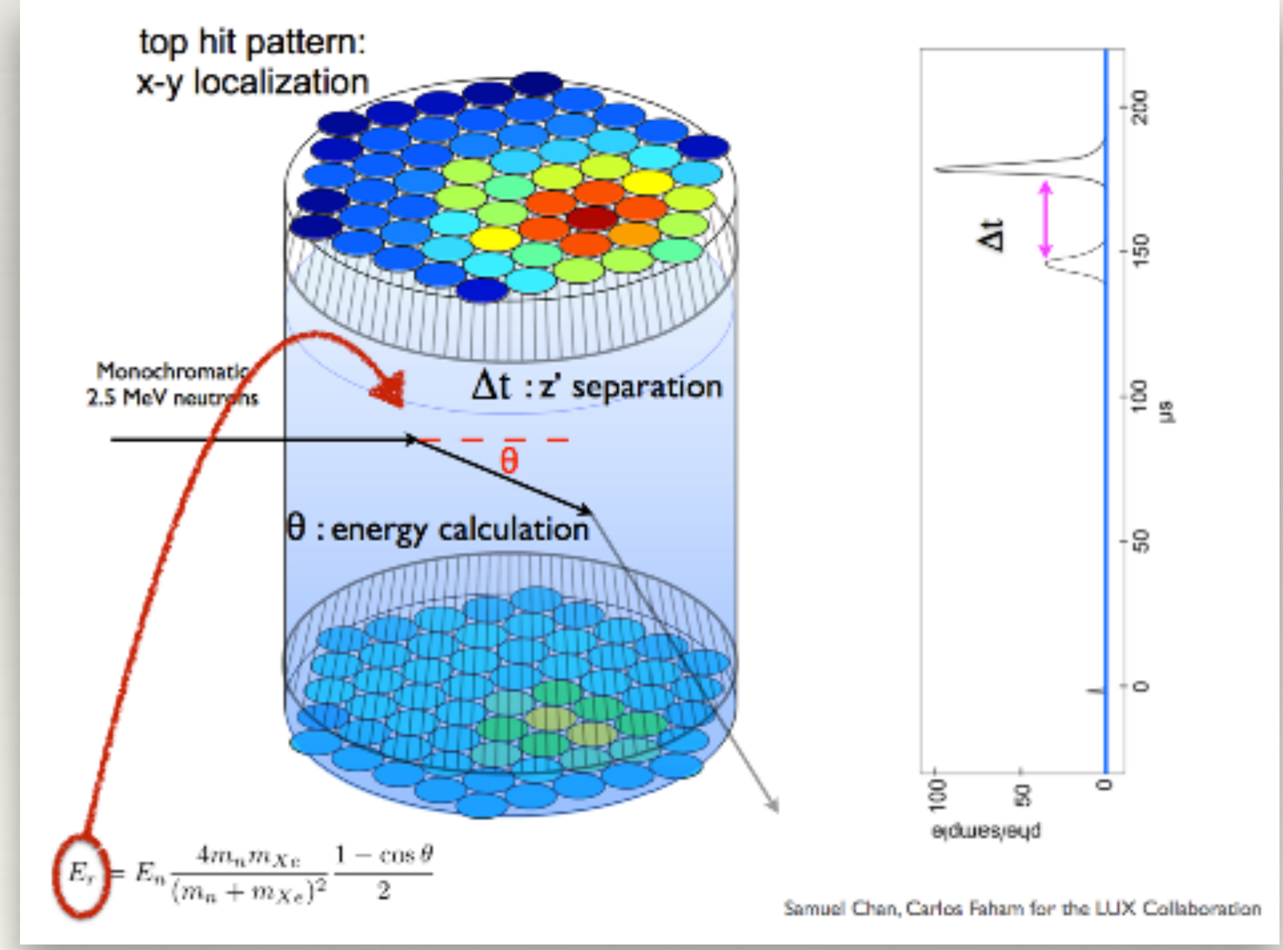


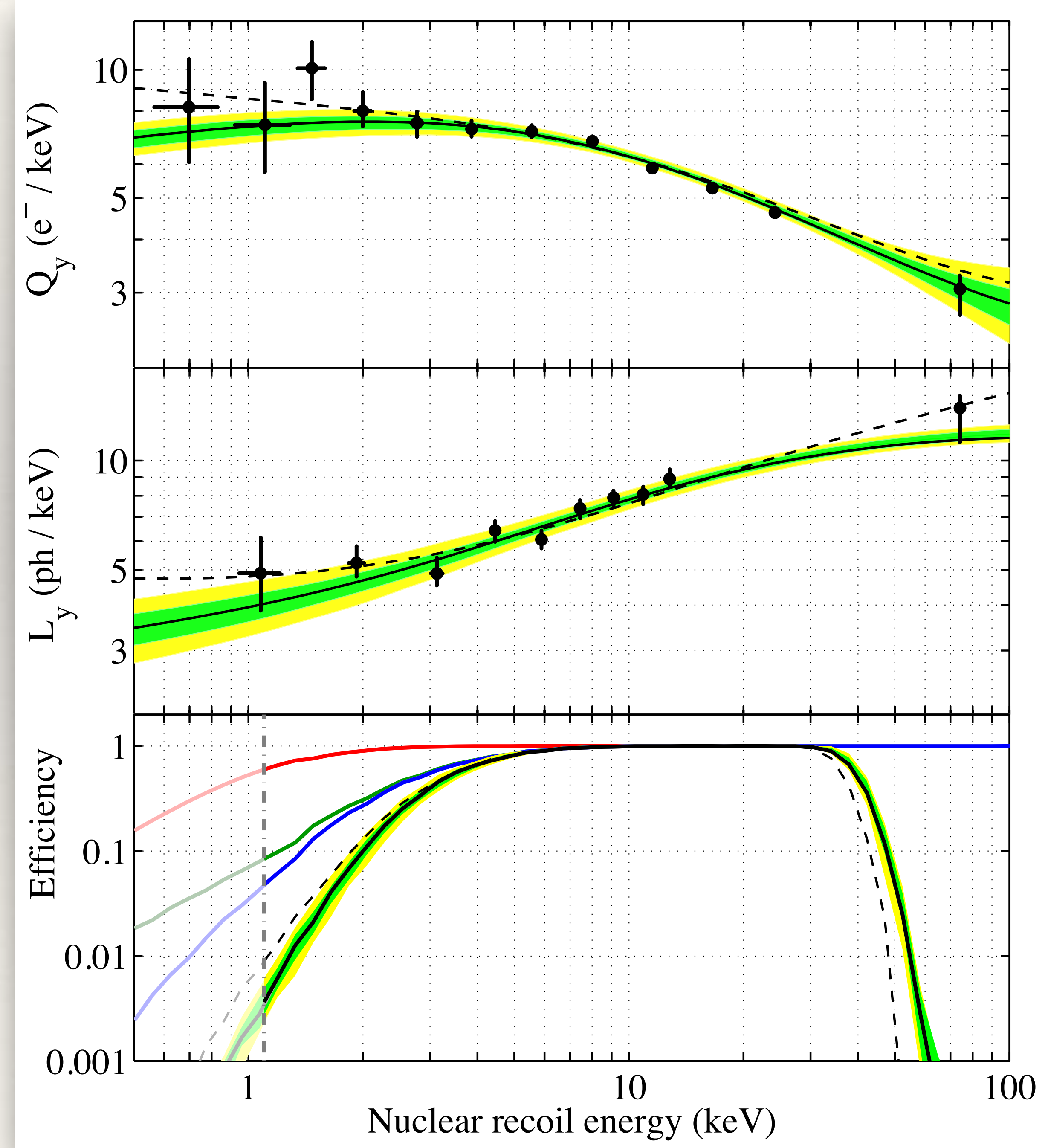


Calibration #3: DD neutrons

In situ Deuterium-Deuterium neutron calibration for nuclear recoils







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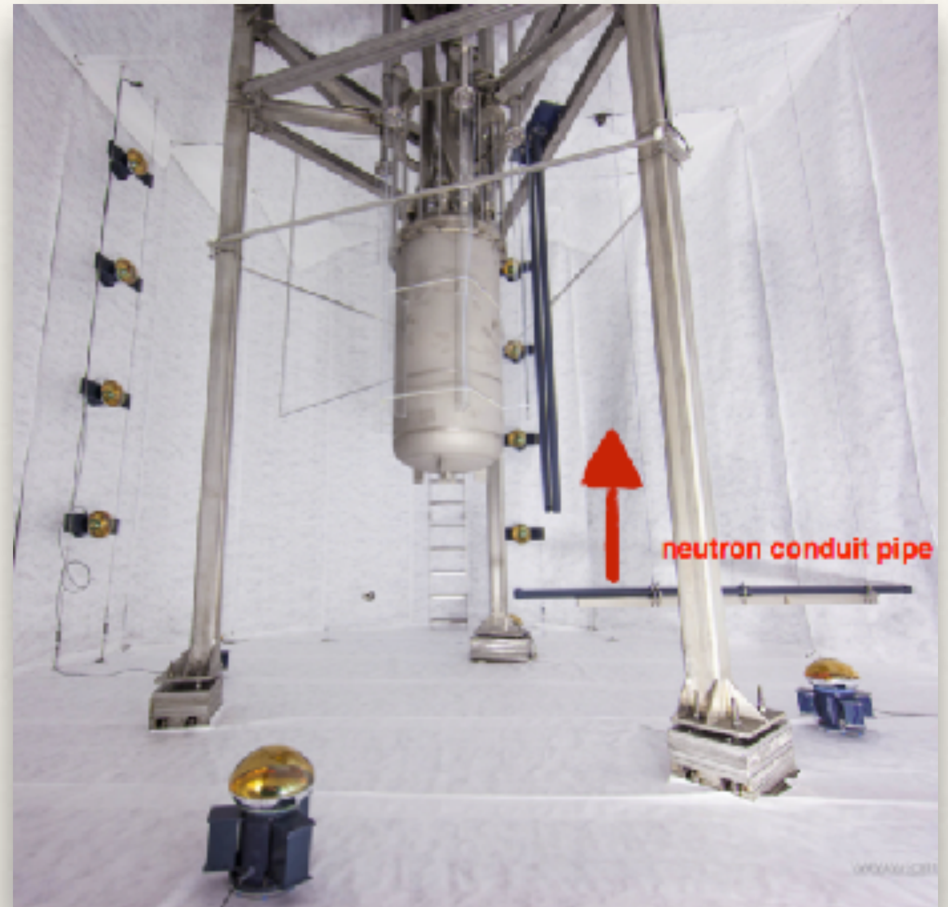

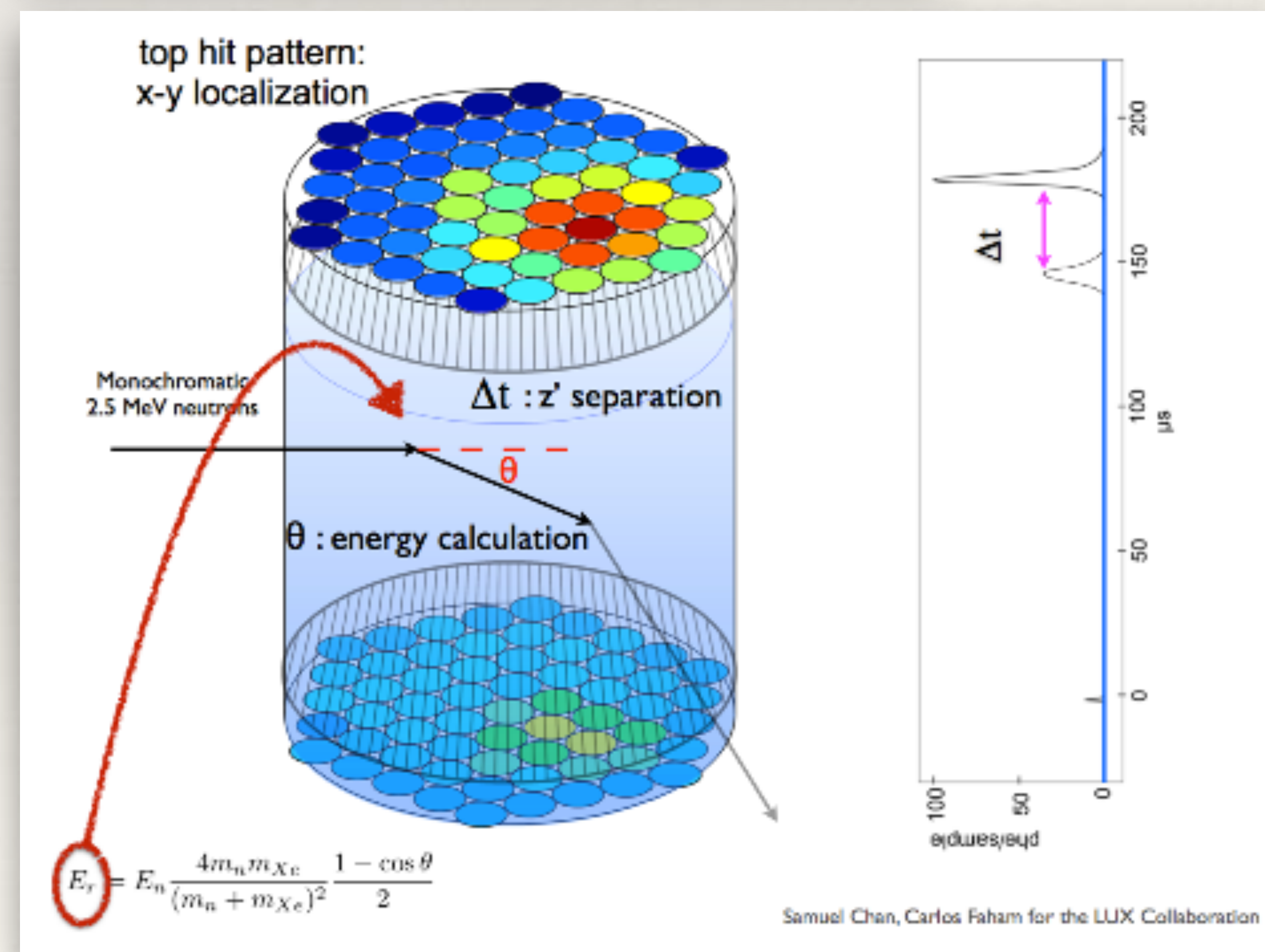

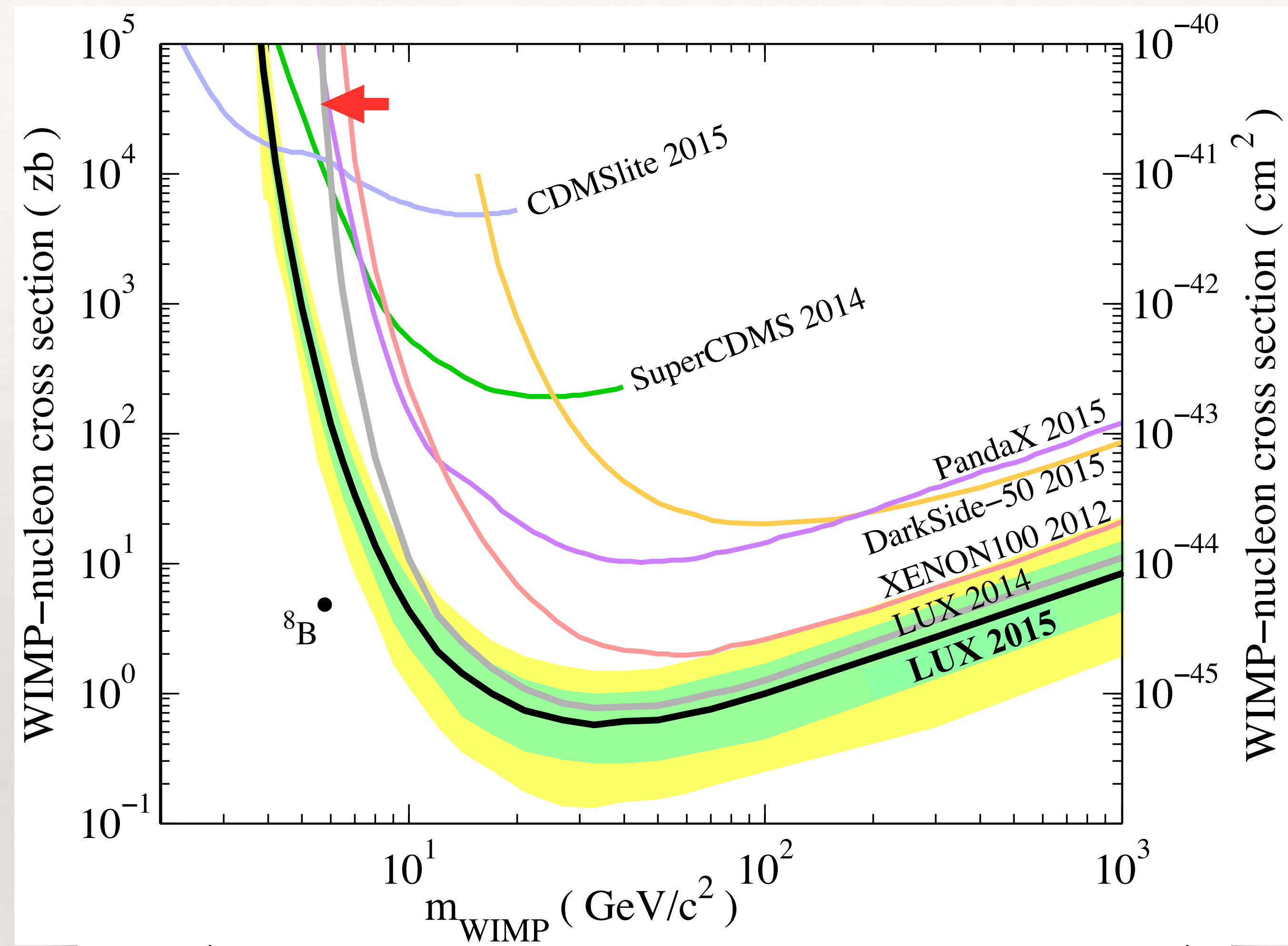

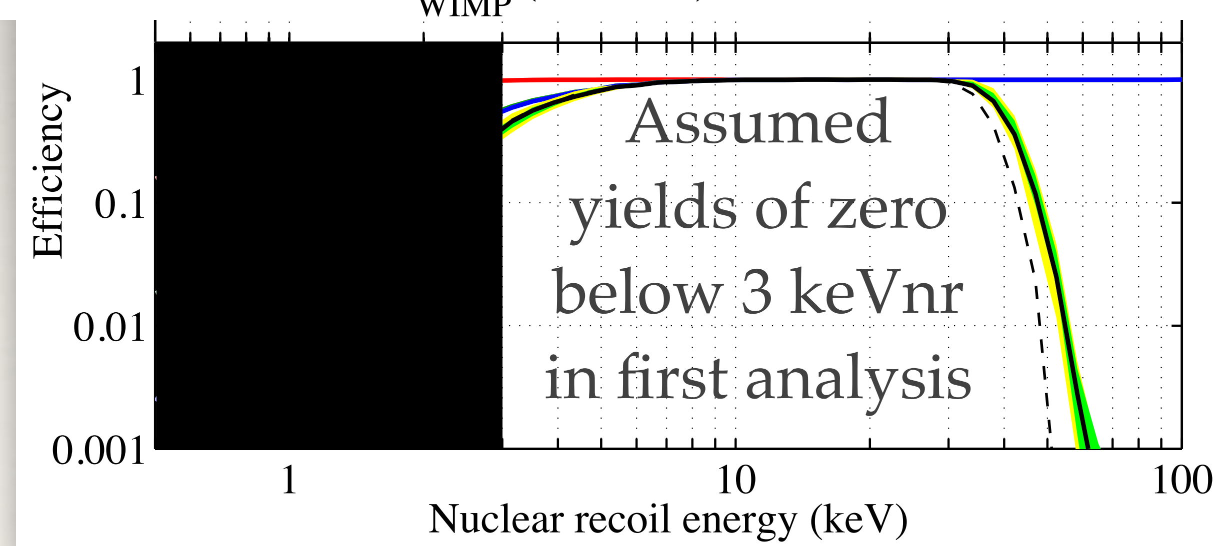

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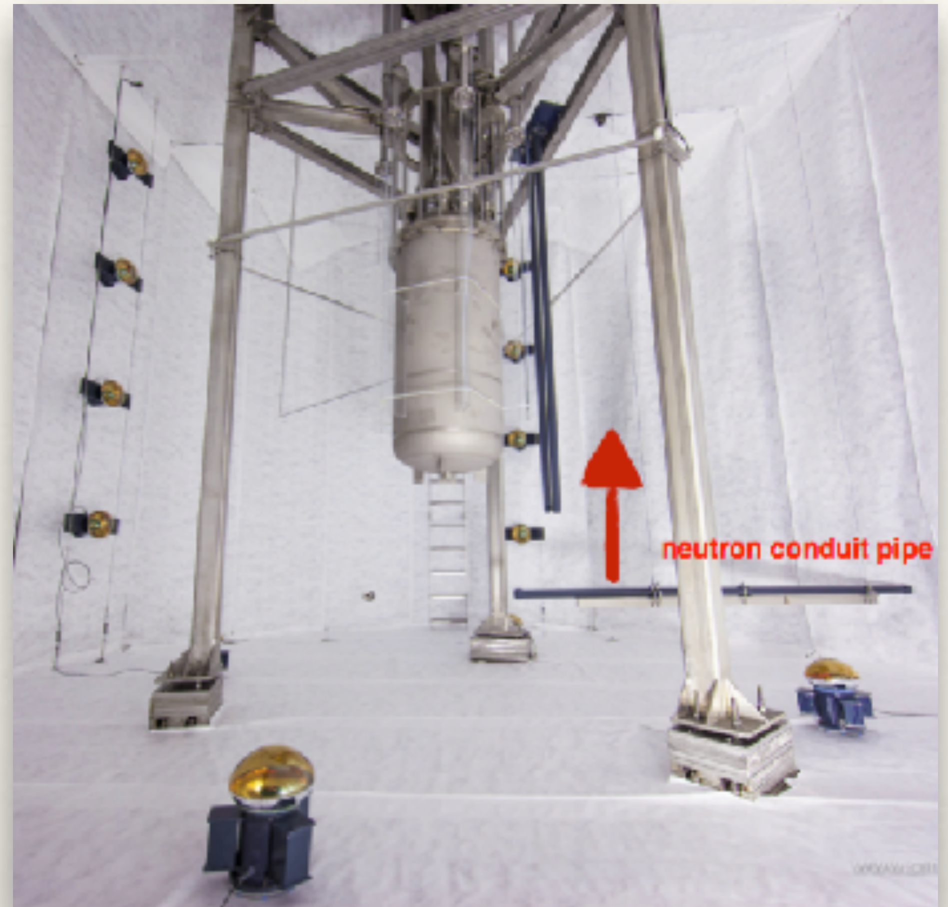
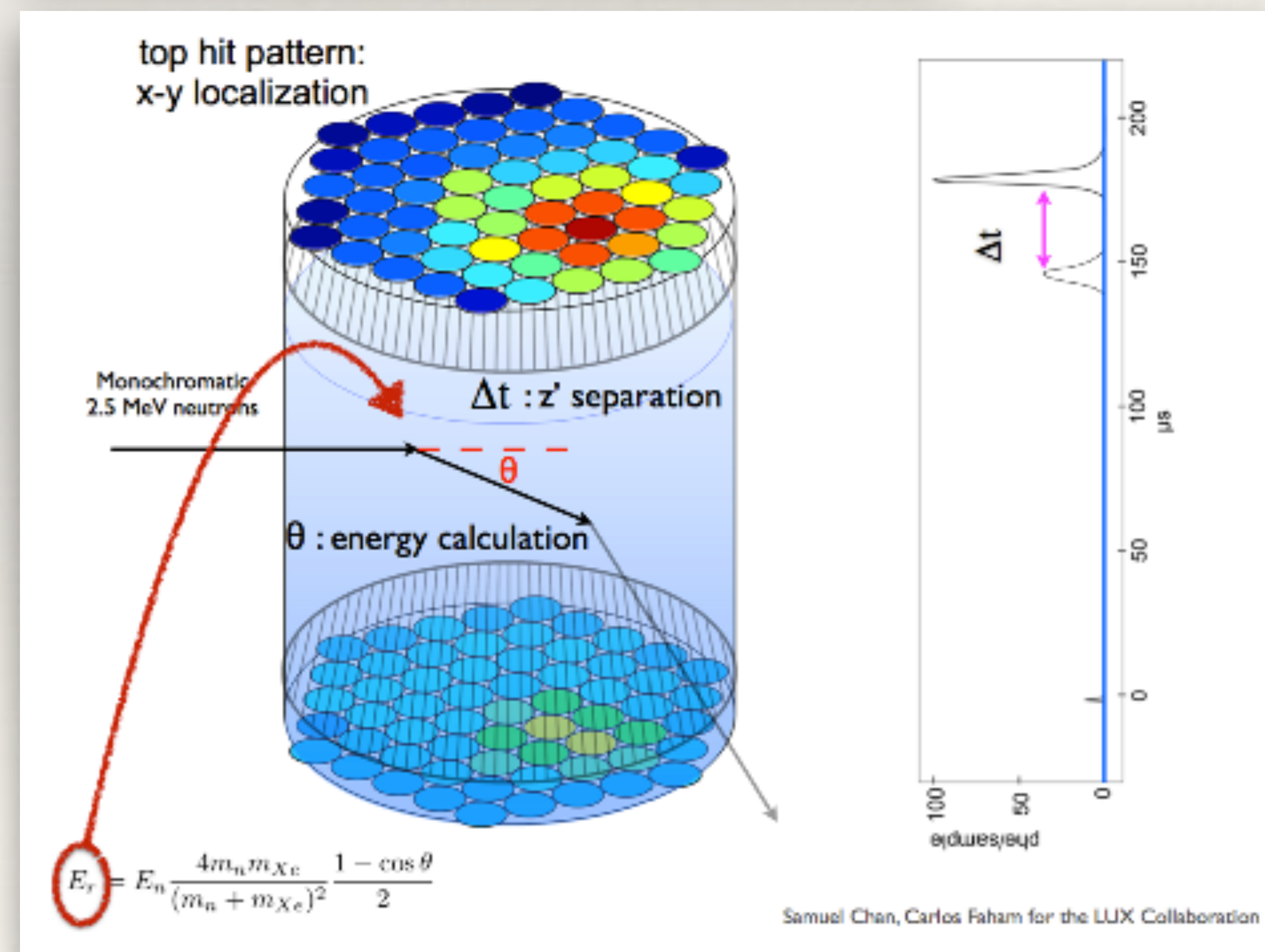
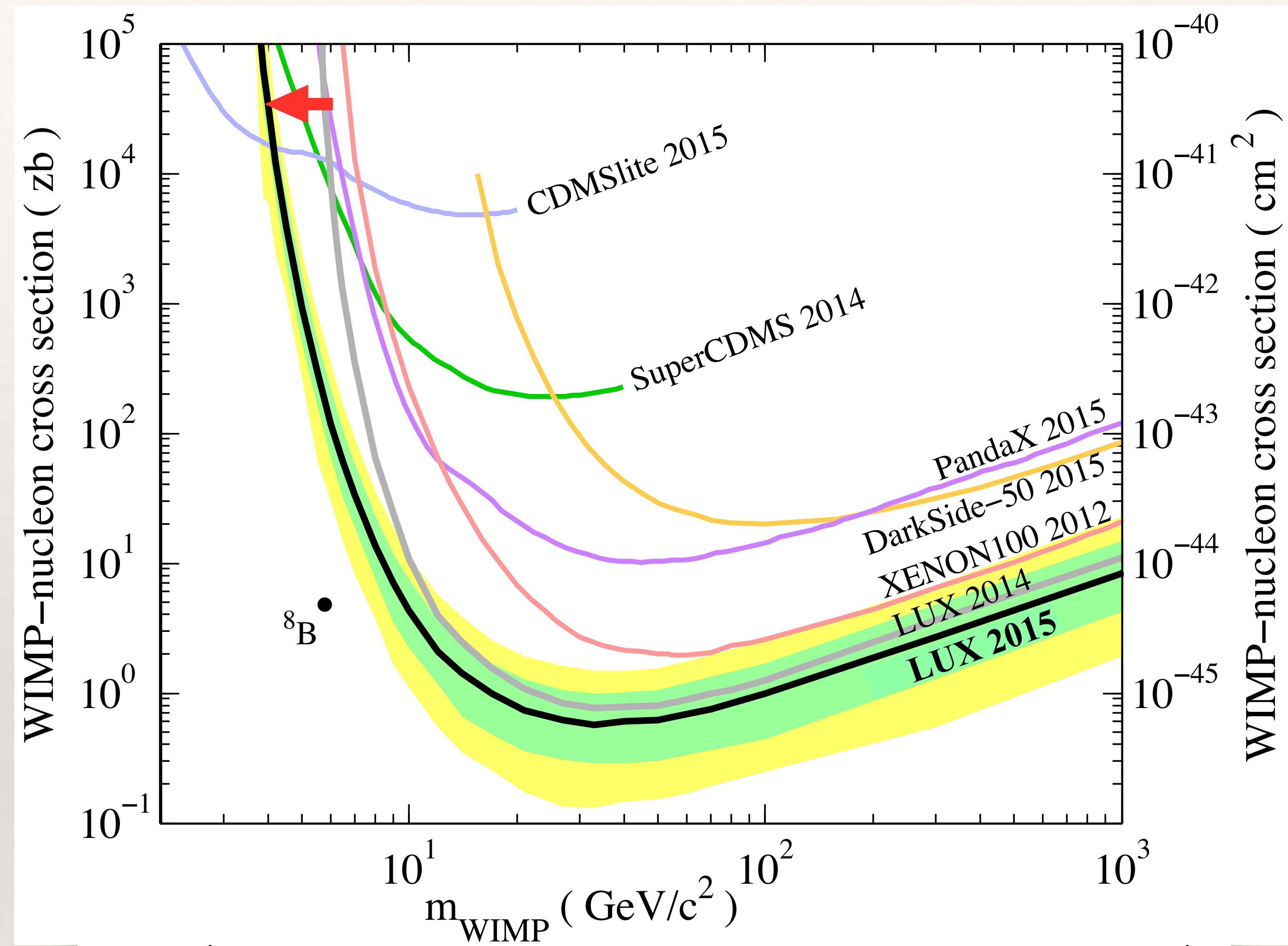
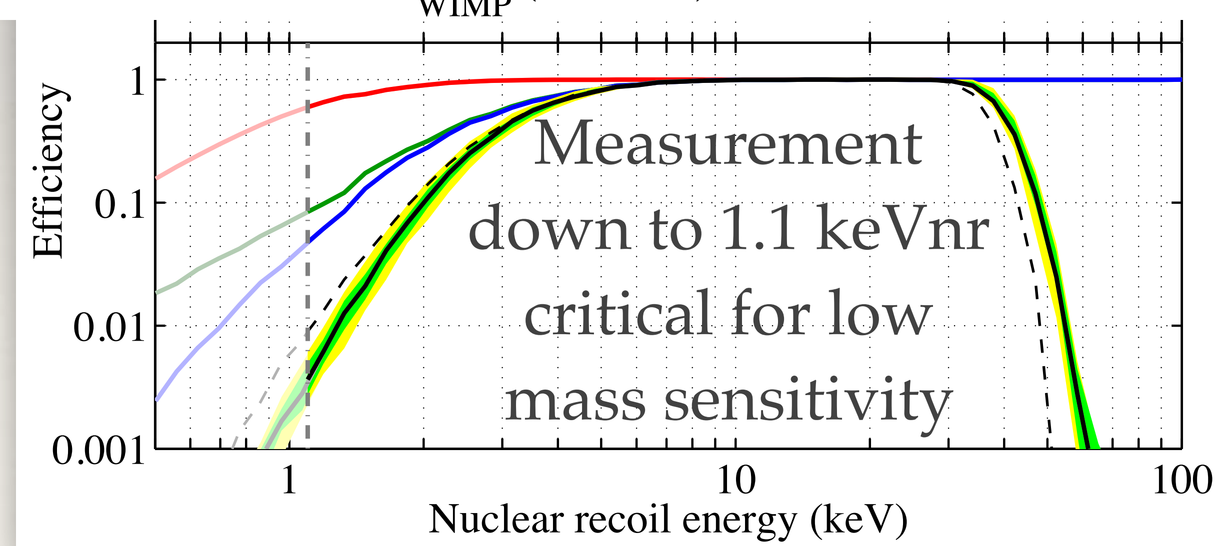








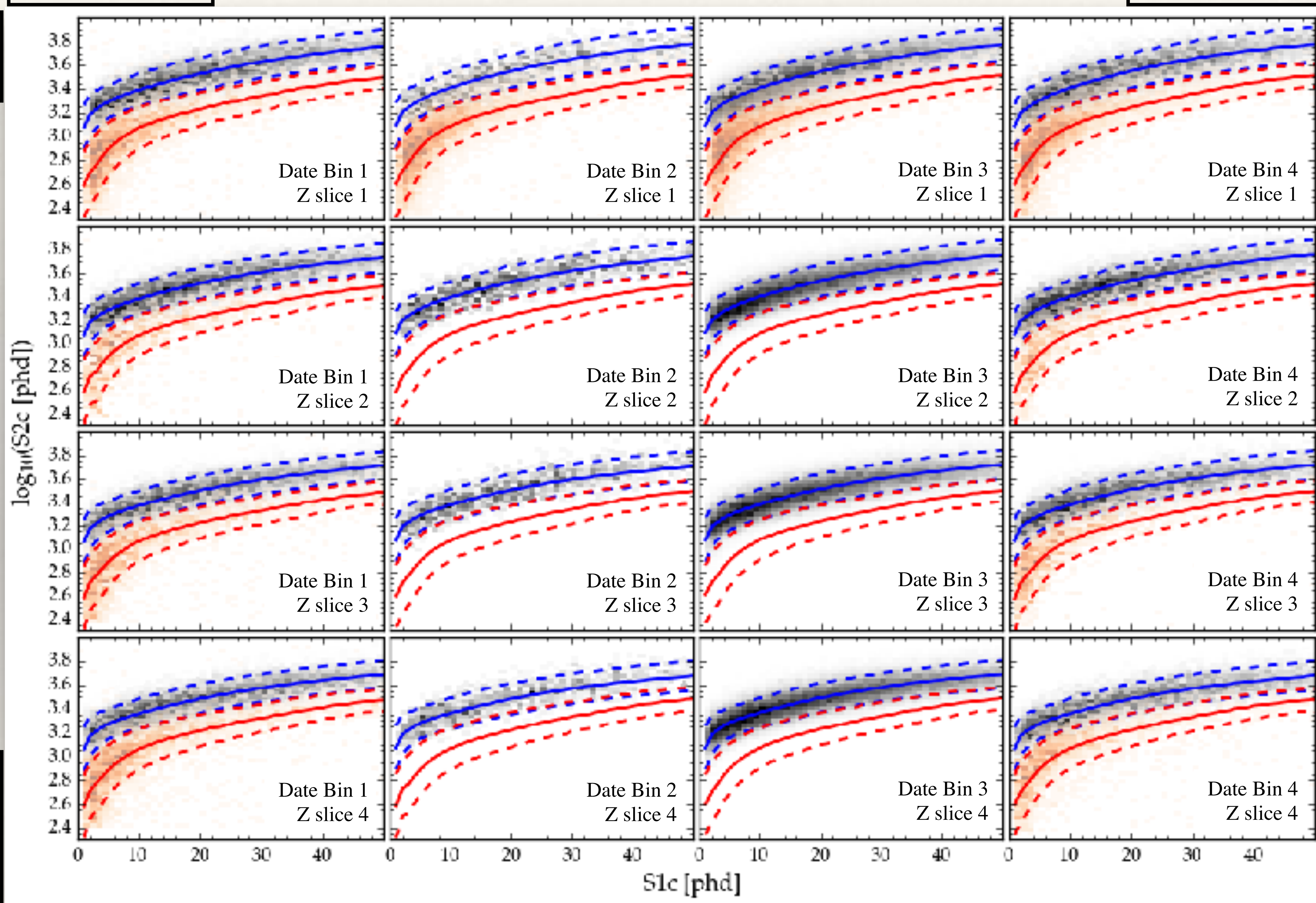
Measurement down to 1.1 keVnr critical for low mass sensitivity

Calibrating and modeling for LUX2014-16

Sept. 2014 ⟷ May 2016

Top

Bottom



Gray density: CH_3T calibration (ER)

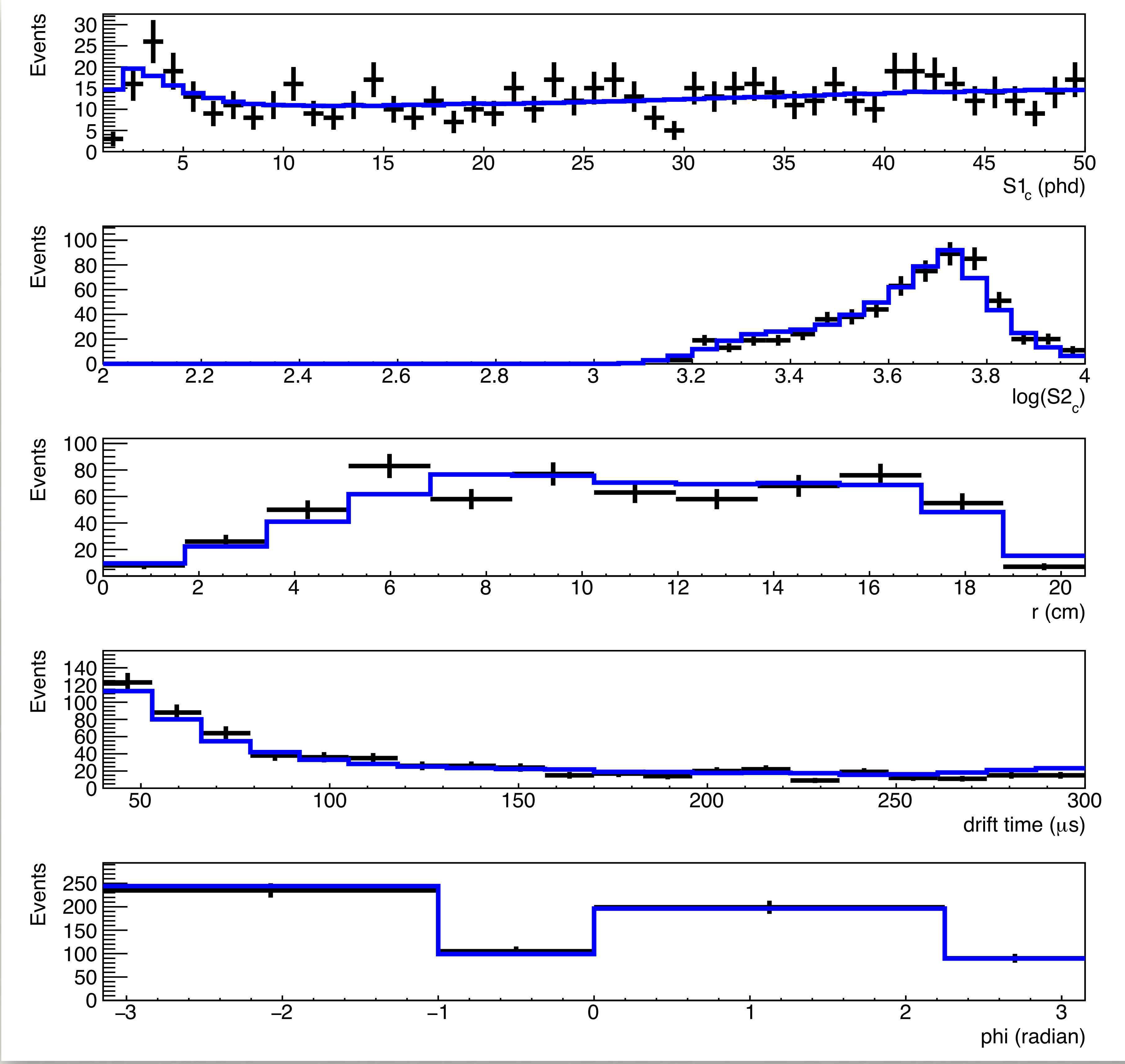
Orange density: DD calibration (NR)

Solid lines: NEST model, ER, NR band mean

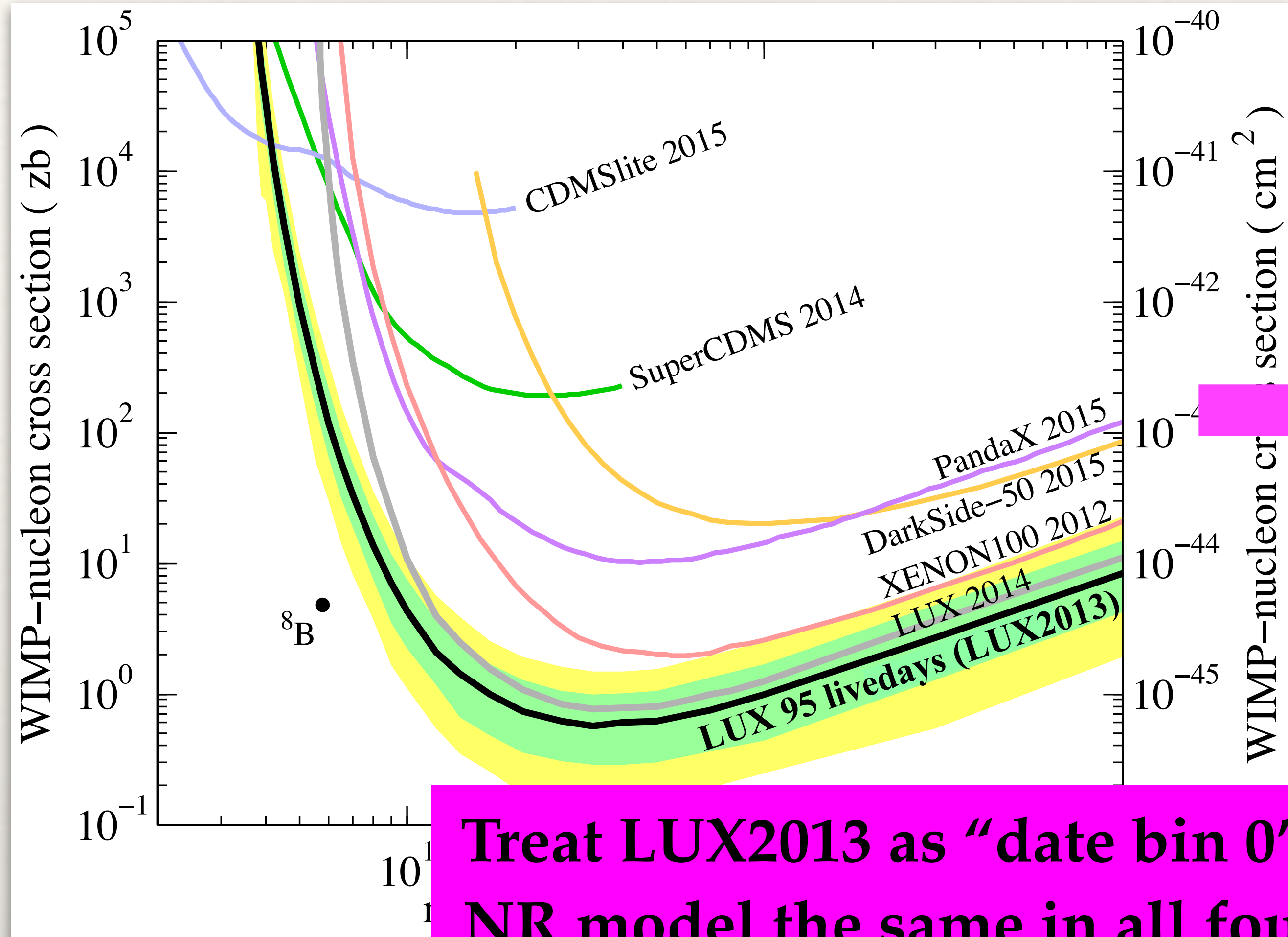
Dashed lines: NEST model, 10-90 percentile.

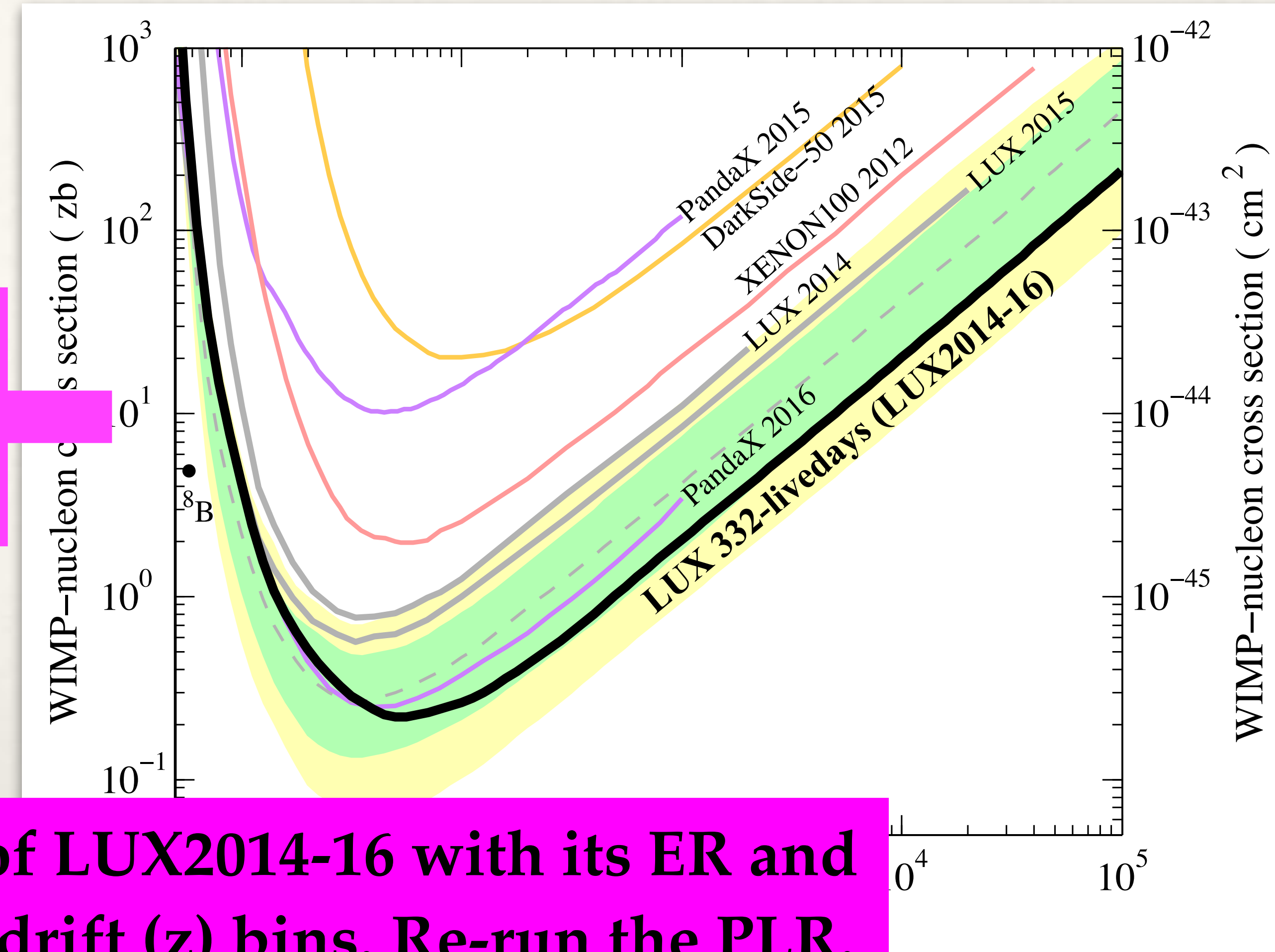
Profile Likelihood Analysis

- Data are compared to models in an un-binned, 2-sided profile-likelihood-ratio (PLR) test.
- 5 un-binned PLR dimensions:
  - Spatial: r, ϕ, drift-time (the S2 coordinates)
  - Energy: S1 and $\log_{10}(S2)$
- 1 binned PLR dimension:
  - Event date
- The data in the upper-half of the ER band (BG-only region) were compared to the model (plot at right) to assess goodness of fit.

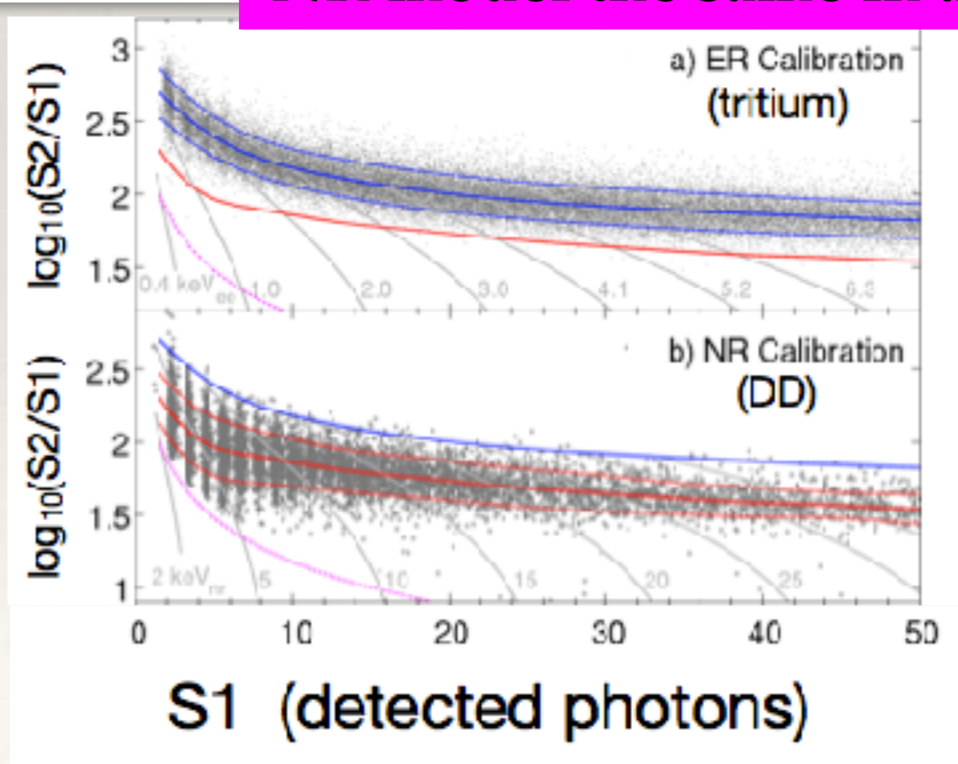


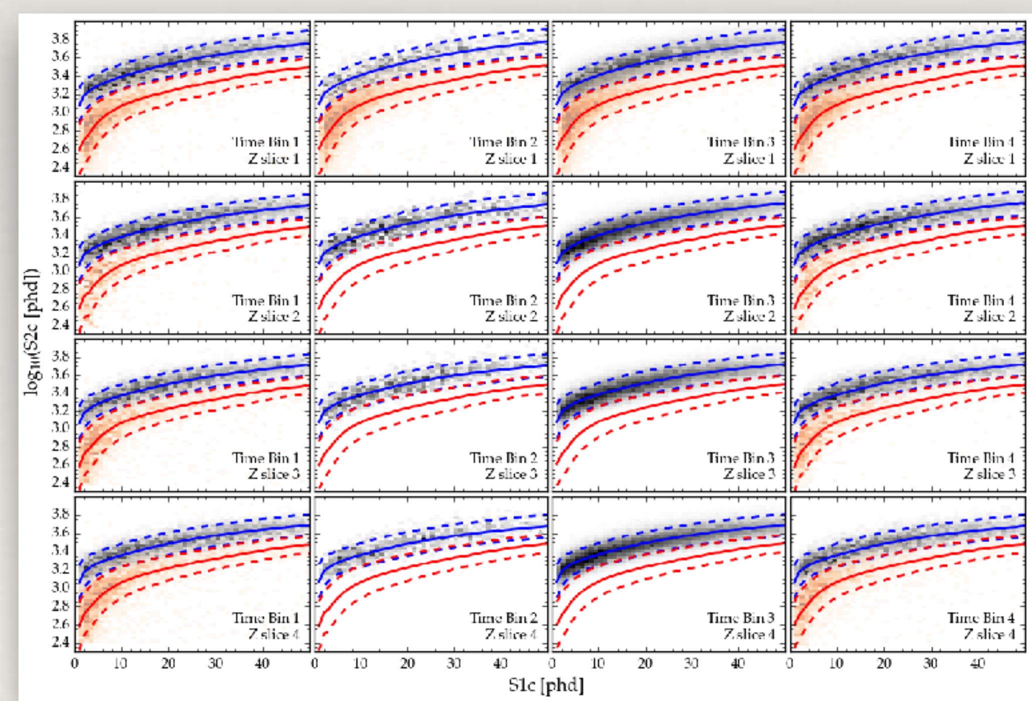
Full exposure spin-independent WIMP-nucleon exclusion





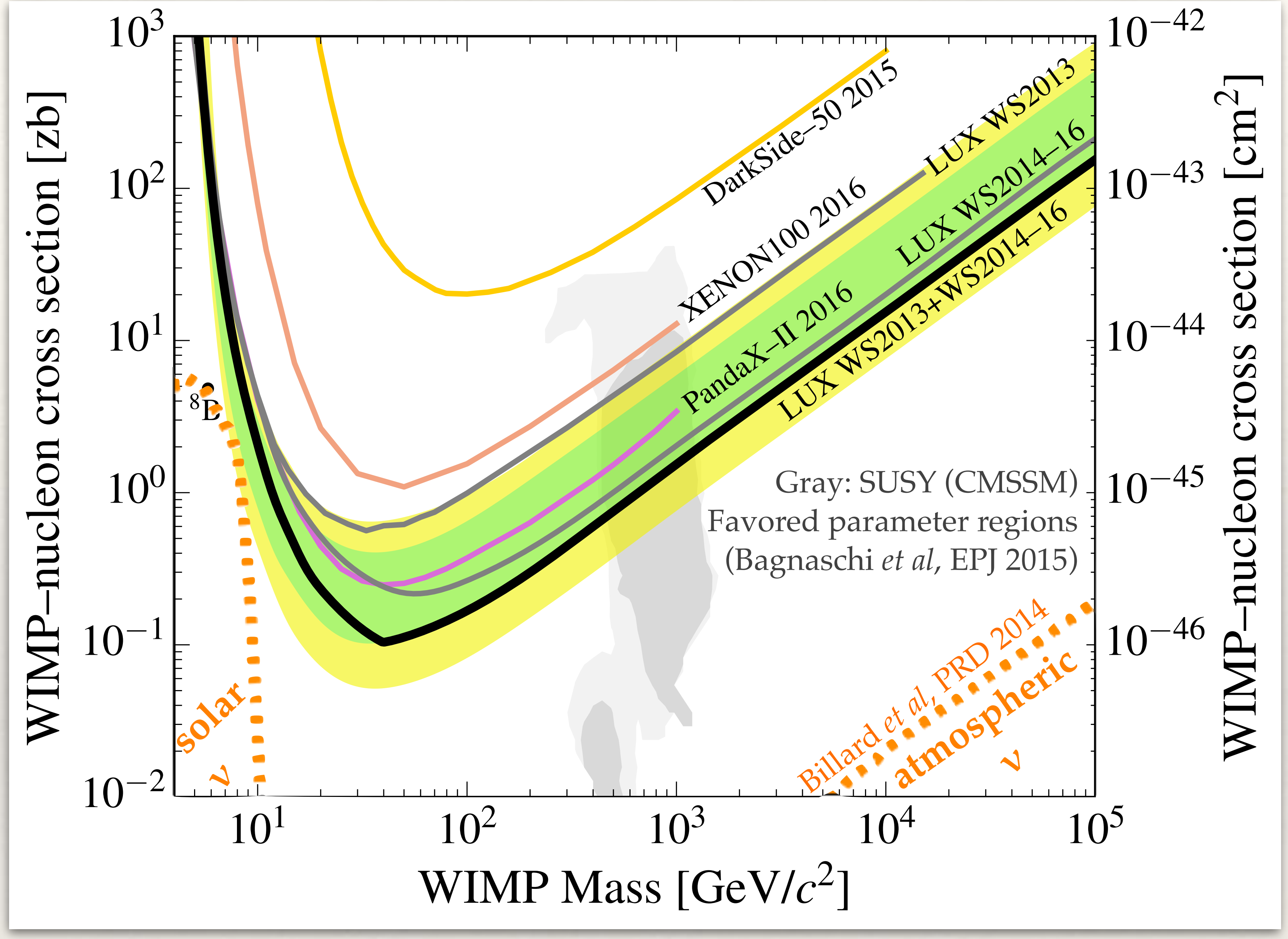
Treat LUX2013 as "date bin 0" of LUX2014-16 with its ER and NR model the same in all four drift (z) bins. Re-run the PLR.





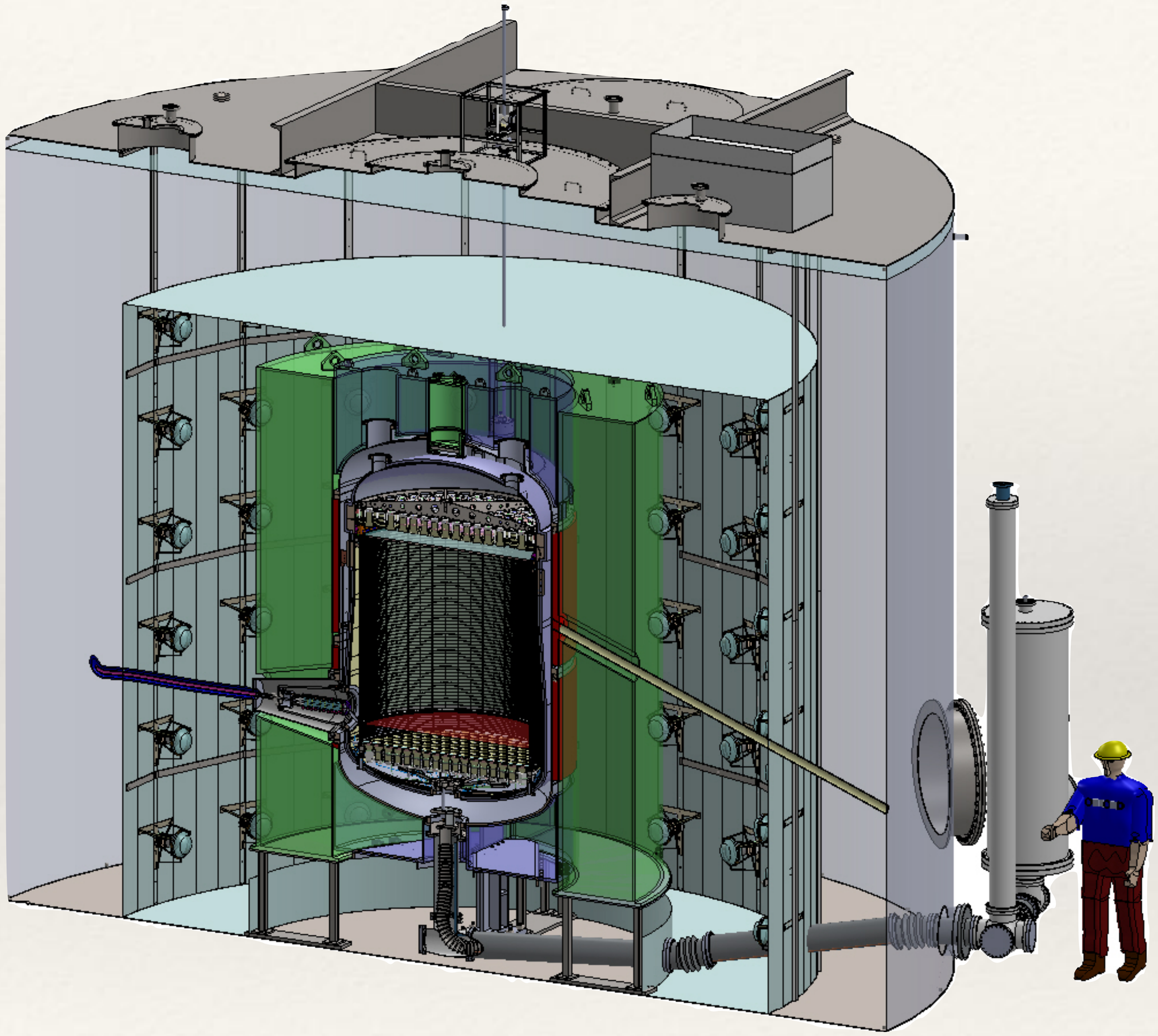
Full exposure spin-independent WIMP-nucleon exclusion

- The full LUX exposure is 4.75 x 10^4 kg·days
  - 130 kg·years
- Minimum of 1.1 x 10^{-46} cm^2 at a mass of 50 GeV/c^2
  - corresponds to 3.2 signal events
  - power constrained at -1σ
- Context:
  - more than 10x improvement upon XENON100
  - More exposure coming from PandaX (~2-5x)
  - XENON1T (~8-10x) and LZ (~100x) on the horizon



Read more!
[arXiv:1608.07648]
(recently accepted by PRL)

The LUX-ZEPLIN detector



LZ (LUX)

Active mass: **7 T (0.25 T)**

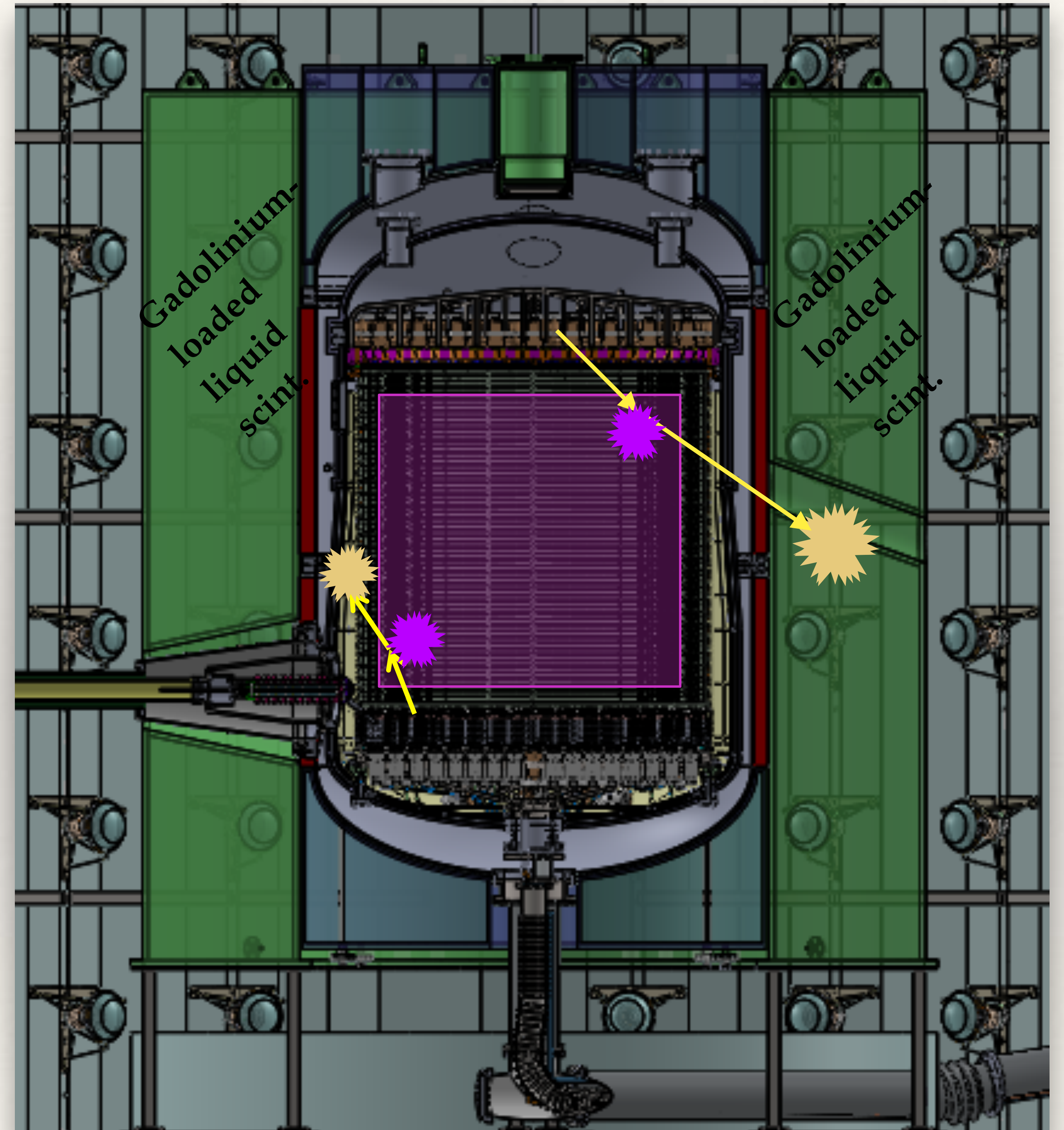
Run time: **1000 d (427 d)**

Minimum σ_{SI}:

1.1e-48 cm² (1.1e-46 cm²)

Fiducial mass: **5.6 T (0.1 T)**

Active veto volumes



- TPC field cage is not pressed up against the cryostat wall for two reasons
  - high fields
  - background rejection

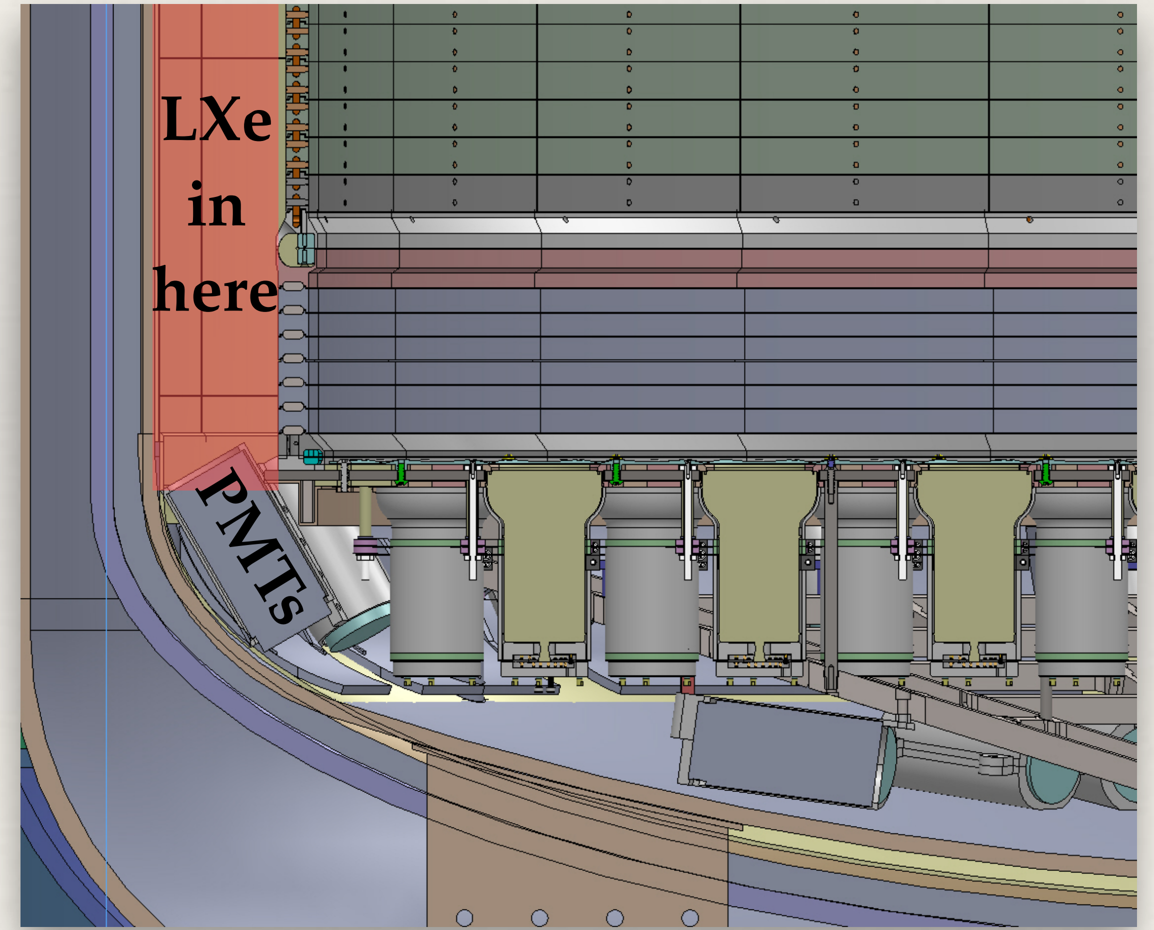


Image from *CPAD* talk by Ethan Bernard, UC Berkeley

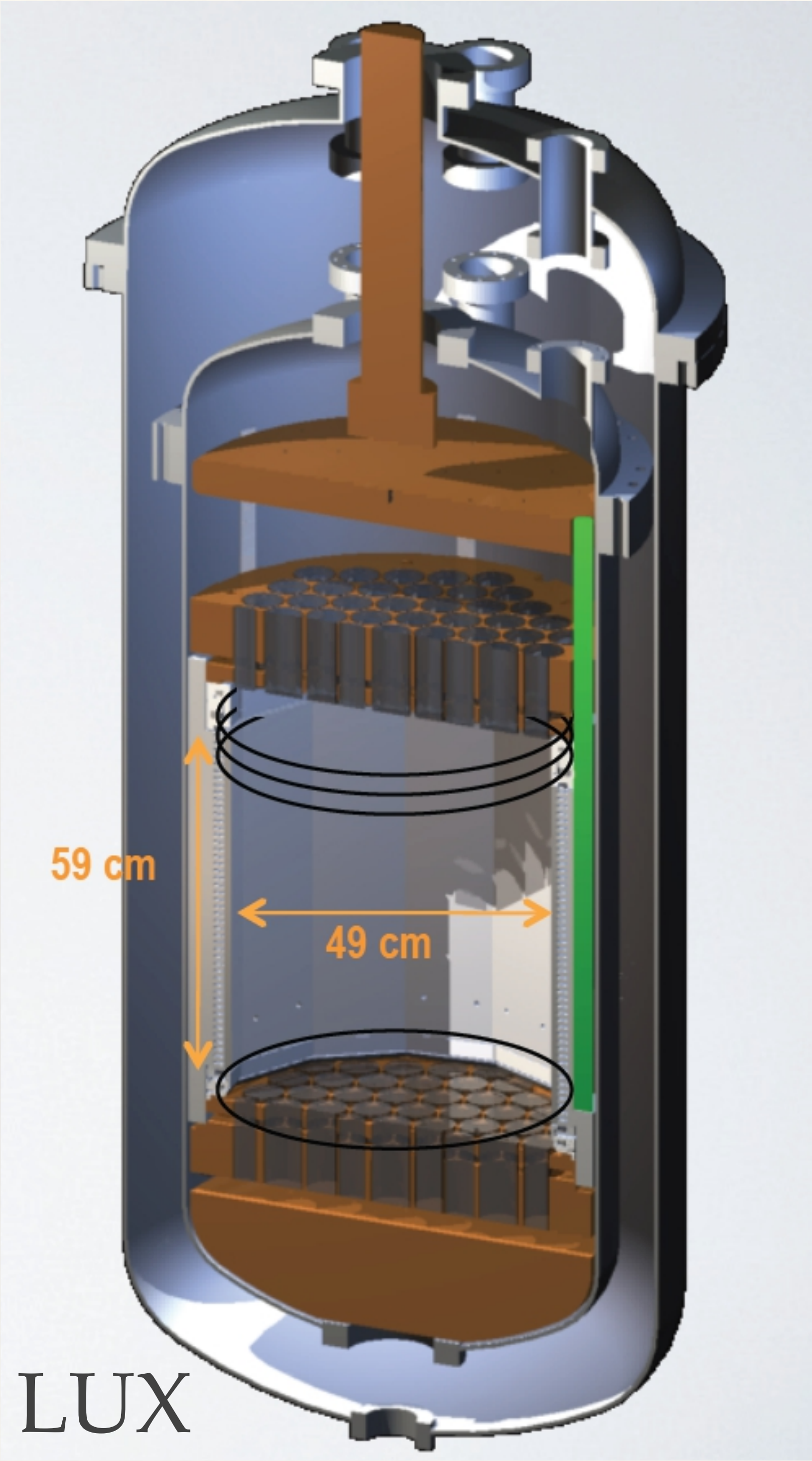
Plans for successful cathode high voltage delivery

Motivation: unintended light production must be avoided.
- field-emission electrons from surface defects on conductors
- uncontrolled buildup of charge on insulators

We know this is hard to do:

Xenon10: data at 13 kV
Xenon100: planned for 30 kV; data at 16 kV
LUX: planned for "up to 100 kV"; data at 10 kV
LZ: 2.5x LUX drift length! Designing for 100 kV with requirement of 50 kV

A simple 2.5x-scale-up of LUX does not work…
- high fields between TPC wall and cryostat
- high fields between cathode and bottom PMTs
- high fields around the cathode feedthrough



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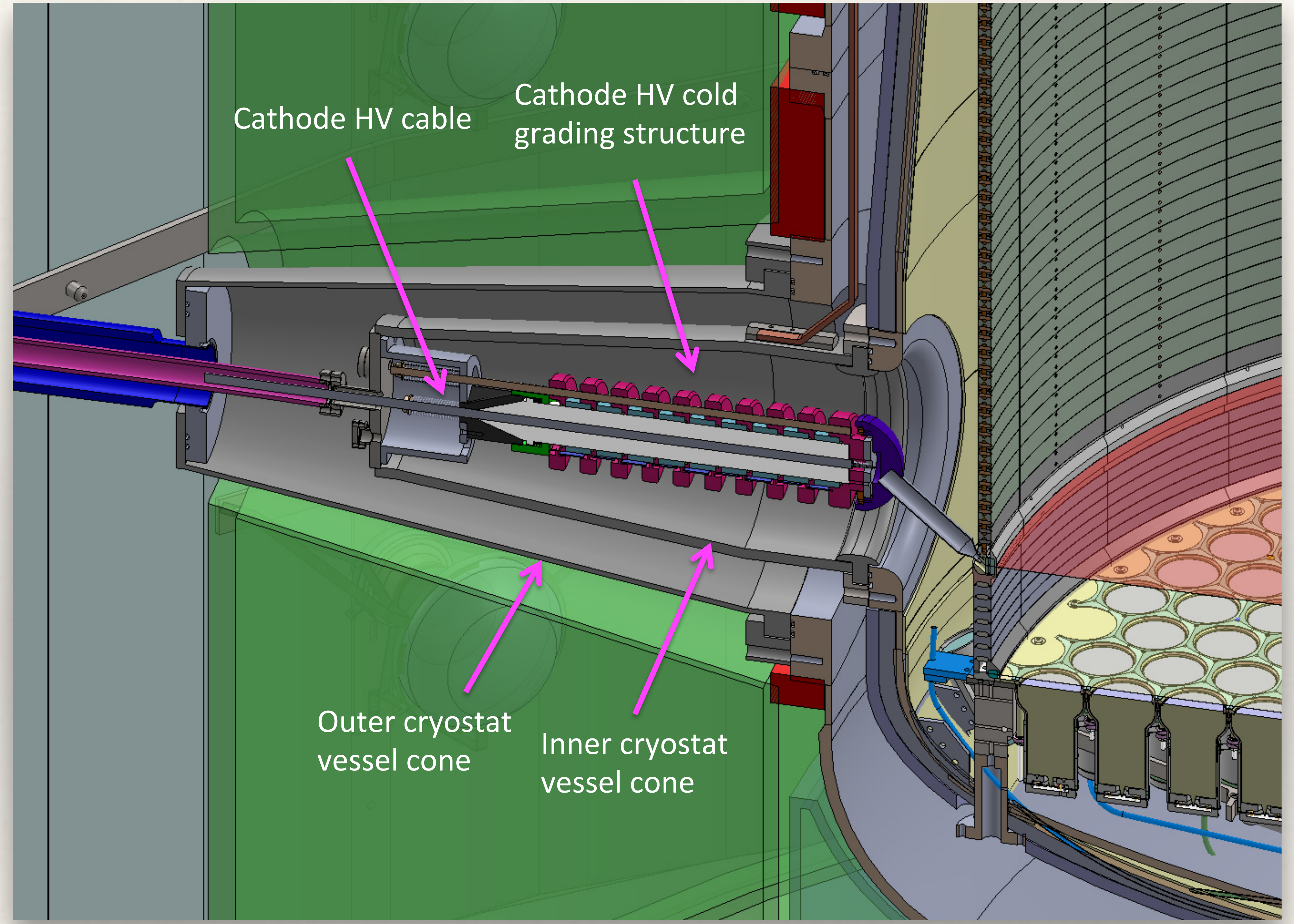


Image from *CPAD* talk by Ethan Bernard, UC Berkeley

- 50 kV baseline voltage with a goal of 100 kV
  - LZ: 300 (600) V / cm
  - LUX: 180 V / cm
- Controlled grading of potential between HV cable ground braid termination and center conductor connection to LZ cathode
- Flared inner cryostat allows more space, meaning lower fields around TPC field rings with the highest voltage
- Extensive field simulations to minimize peak fields in LXe

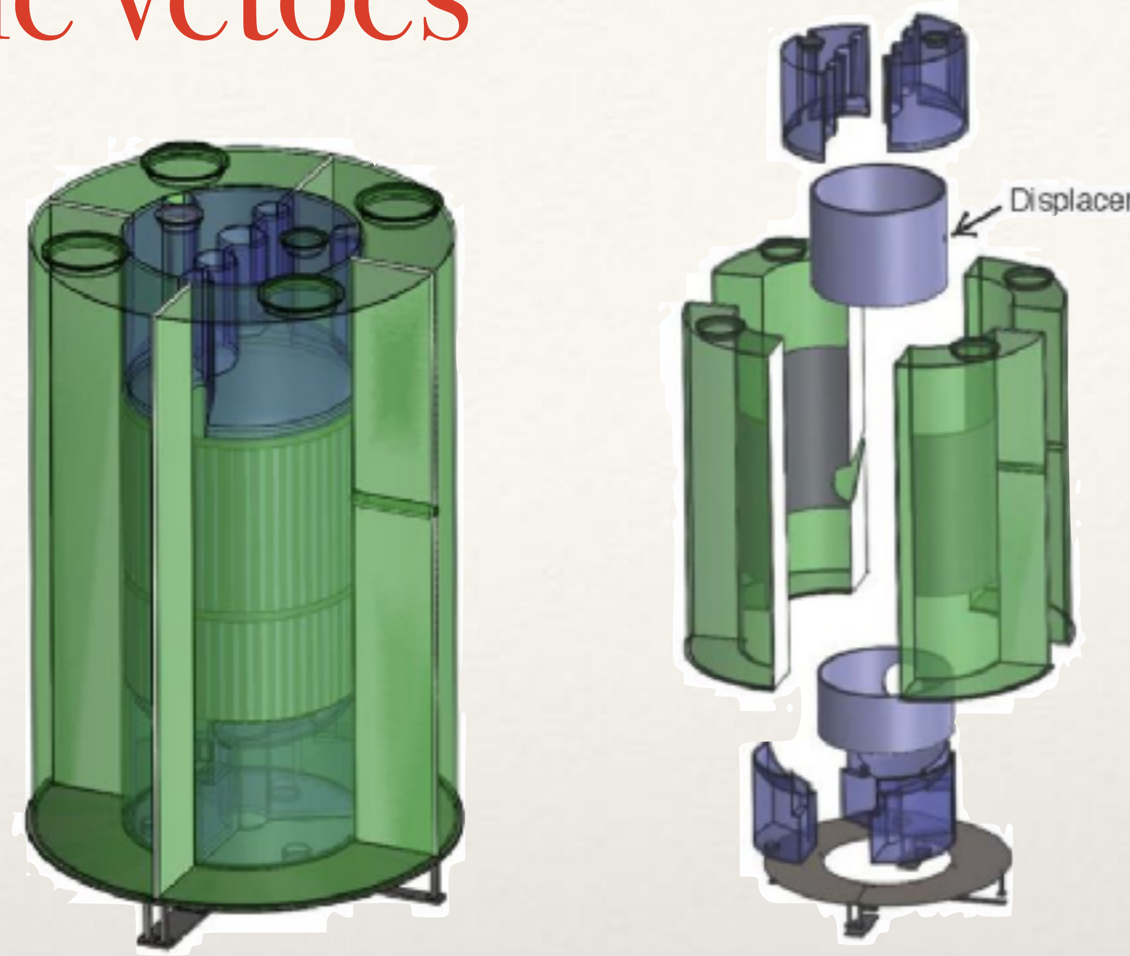
Effect of the vetoes

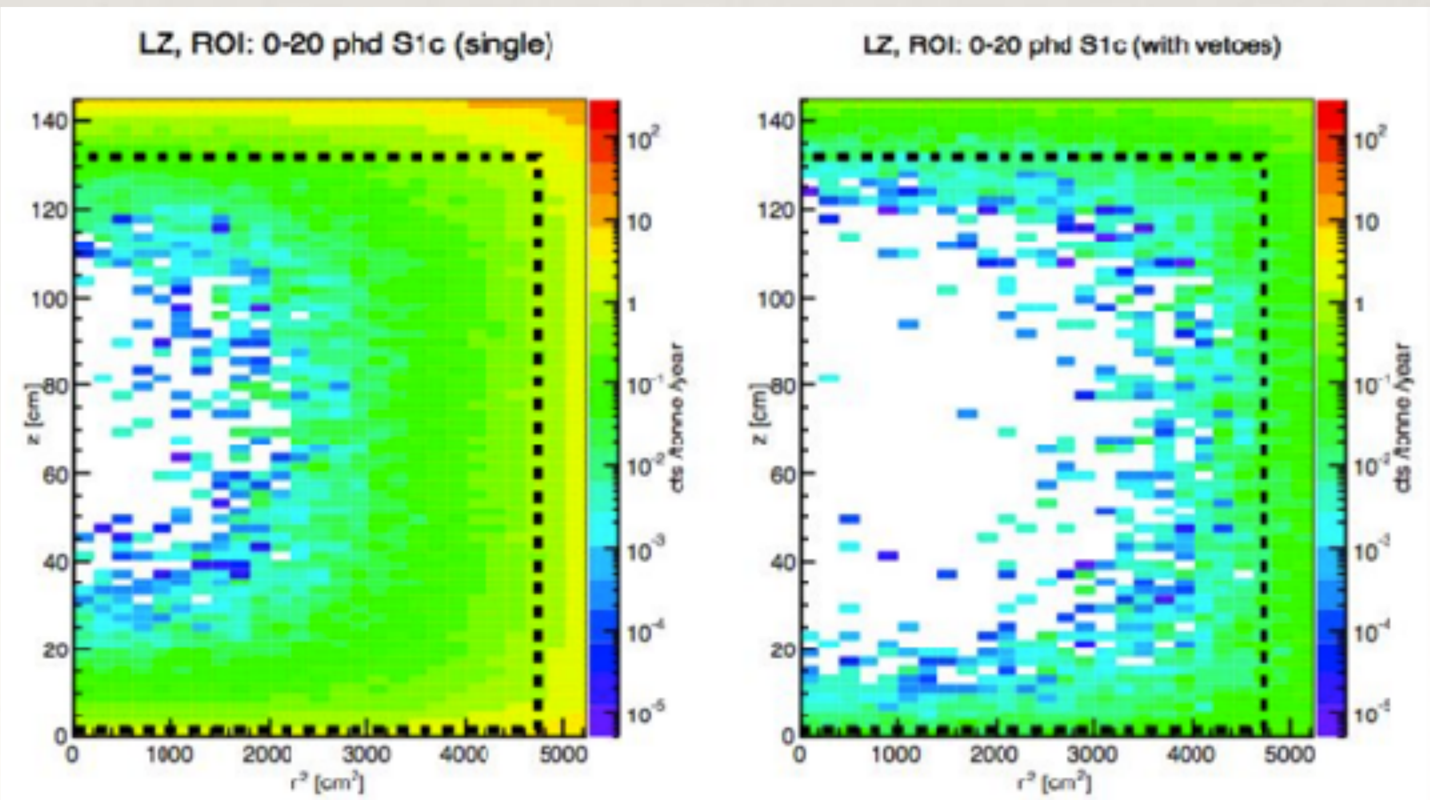
- Nine acrylic tanks, 60 cm thick, holding 17.5 tonnes of Gadolinium-loaded scintillator (LAB, linear alkylbenzene)

- 97% efficient for neutron detection

- Borrowing technology for scintillator and tanks (as well as people) from Daya Bay

- In combination with the instrumented LXe "skin," the fiducial mass expands from 3.8 to 5.6 tonnes





Backgrounds

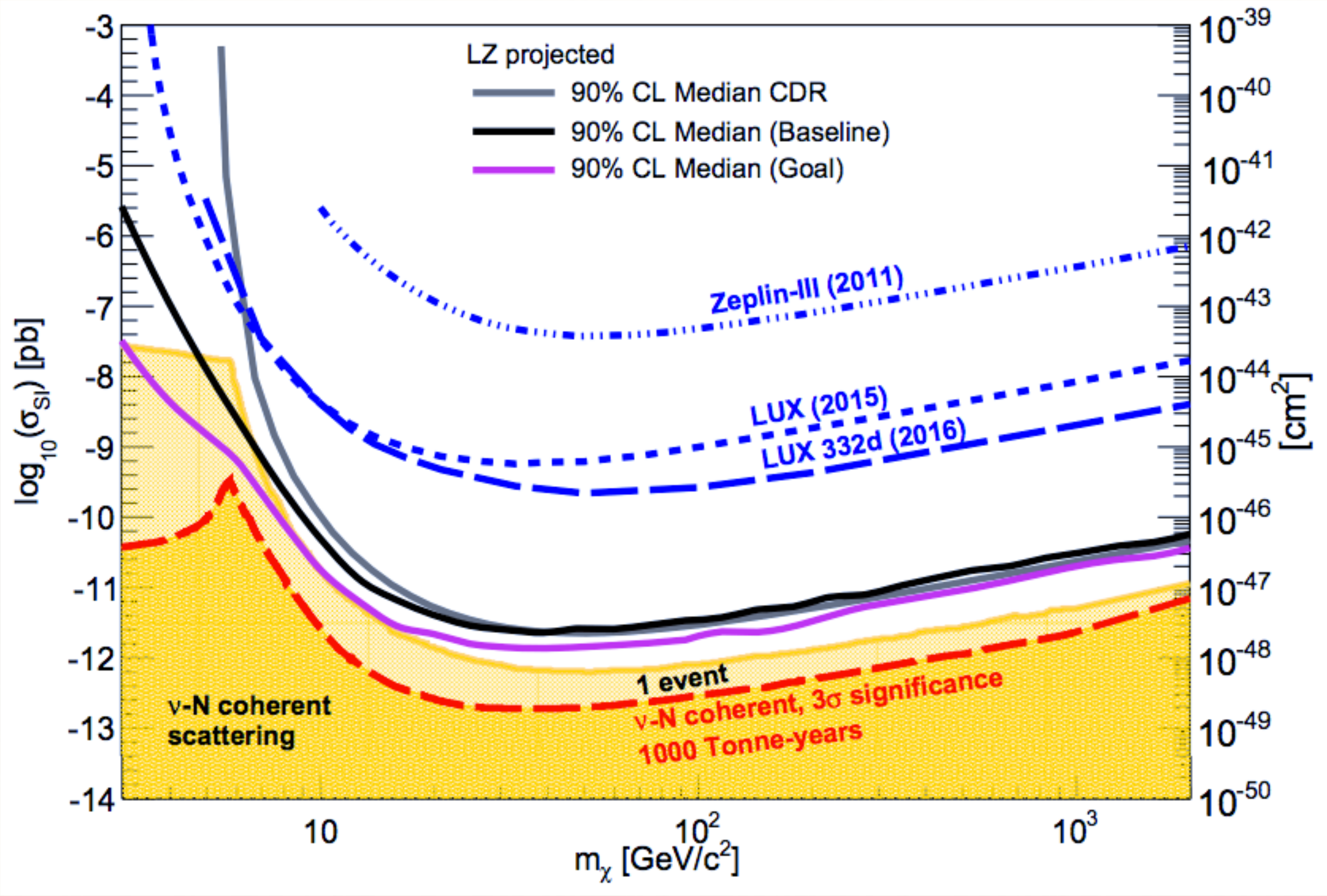
- Vetoes help immensely with the BG from materials. The larger backgrounds then become radon (and krypton)
- Radon
  - Emanates from most materials
  - 20 mBq req., 1 mBq goal
  - Main assembly at SURF will have reduced Rn air system
- Krypton-85
  - Remove to <15 ppq using gas chromatography
  - Setting up to process 200 kg/day at SLAC

Item	Mass (kg)	U (mBq /kg)	Th (mBq /kg)	Co-60 (mBq/ kg)	K-40 (mBq/ kg)	n/yr	ER (cts)	NR (cts)
R11410 PMTs	91.9	71.6	3.1	2.82	15.4	81.83	1.46	0.013
R11410 bases	2.8	287.7	28.4	1.43	69.4	34.65	0.36	0.004
Cryostat vessels	2406	1.6	0.29	0.07	0.6	123.70	0.63	0.013
OD PMTs	204.7	570	395	0	534	7587	0.01	0.000
Other components							3.74	0.04
Total components							**6.20**	**0.070**
Dispersed radionuclides (Rn-222, Rn-220, Kr-85)							911	-
Laboratory and cosmogenics							4.3	0.06
Surface contamination							0.19	0.37
Xe-136 2vBB							67	-
Neutrinos (v-e, v-A)							255	0.72
Total events							1240	1.22
WIMP BG events (99.5% ER discrimination, 50% NR acceptance)							6.22	0.61
Total ER+NR background events							**6.82**	

LZ Past, Present, Future

Year	Month	Activity
2012	March	LZ (LUX-ZEPLIN) collaboration formed
	September	DOE CD-0 for G2 dark matter experiments
2013	November	LZ R&D report submitted
2014	July	LZ project selected in US and UK
2015	April	DOE CD-1/3a approval; begin long-lead procurements
2016	August	DOE CD-2/3b approval 🎉 🎉 🎉
	October	LUX removed from SURF 4850′
Today		
2017	January	DOE CD-3 review planned
	August	Beneficial occupancy for surface assembly building
2018	June	Beneficial occupancy for underground installation
2019		Underground installation
2020	April	Start operations
2025+		5+ years of underground science

Projected sensitivity (1000 days)



Summary and next steps

- **LUX** has excluded SI WIMP-nucleon cross-sections down to **0.11 zeptobarns** (at a mass of 50 GeV/c^2)
  - Full exposure search is on arXiv and accepted for publication in PRL
- More LUX results from 3+ years of UG operation on the way
  - DM: improved spin-dependent sensitivity, new axion/ALP, EFT, …
  - There is a lot more still to learn from LUX data!
- **LUX-ZEPLIN (LZ)** experiment is approaching construction
  - 7000 kg active mass, 100x LUX sensitivity, starting in 2020
  - Multiple instrumented vetoes for background minimization
  - Cleanliness protocols being followed to minimize Rn, the largest background
  - Cryostats, PMTs, and outer detector are in production; Xe is being acquired
  - CD-3 in January 2017